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Estimating the 'Coordinated Effects' of Mergers*

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Abstract

Mergers can be blocked if they increase the likelihood of coordination. This paper presents the first empirical coordinated effects merger simulation model in a differentiated product market. We study the network server market. We find that the incentives to coordinate actually fell as a result of the merger between HP and Compaq and show, contrary to conventional economic logic, that incentives to coordinate will ceteris paribus often fall in this way after a merger. We extend the model to empirically examine the impact of multi-market contact, a competitive fringe, and the presence of an antitrust authority imposing punishments on tacit colluders in the form of fines.

Keywords: Antitrust, Mergers, Coordination, Coordinated Effects, Joint Dominance, Network Servers, Computers, Oligopoly, Differentiated products.

JEL Classification: L1, L4, L63

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1 Introduction

This paper empirically evaluates the incentives firms face to tacitly collude in differentiated product markets and how they change following a merger. Both academics[1] and regulators[2] have recognized that mergers can potentially facilitate tacit collusion by changing the incentives firms face when setting prices.[3]

The intuition that mergers can result in coordinated effects is often described using Friedman (1971). Specifically, if N is the number of firms, δ is the discount rate and firms follow grim strategies, then industrial organization textbooks argue that collusion will be sustainable with N symmetric firms if $V^{Collusion} = \frac{\pi^{monopoly}}{(1-\delta)N} > \pi^{defection} + \frac{\delta\pi^{Nash}}{(1-\delta)} = V^{Defection}$ where π^{Nash} and $\pi^{defection}$ respectively represent the profits to a firm under static Nash behavior and to a firm who is assumed to successfully cheat for one period. Since an individual firm's share of monopoly profits is declining in N, this relationship suggests that generically mergers, falls in N, will make coordination easier to sustain. As we shall describe, our empirical results found the opposite to be true and so we considered the extent to which this intuition is in fact helpful for policy makers. In what follows, we show that this intuitive result is, in large part, misleading. Moreover, the elementary version of this theory will generally predict precisely the opposite - that mergers will make tacit collusion harder to sustain, not easier. We establish this theoretical result in Proposition 1 and discus the intuition for our results there.

In this paper, we construct an empirical model following a number of central aspects of Friedman (1971) closely, notably by assuming grim strategies (rather than optimal punishments; Abreu (1986, 1998); Abreu, Pearce and Stachetti (1990)). However, we must generalize the textbook model in a

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[1] Chamberlin (1929) argued this point informally, while Stigler (1964) and Friedman (1971) formalized this intuition in the theory of repeated games. Following Stigler (1964), in order to sustain collusion firms must be able to (i) come to an agreement (which can be difficult when products are complex and differentiated), (ii) monitor each others' behaviour (in order to detect undercutting) and, of course, (iii) enforce collusive behavior collectively by punishing the cheating firms. See Aumann (1985, 1989) and Mertens (1987) for surveys.

[2] See for example the EU, UK or US Horizontal Merger Guidelines.

[3] Recent examples where antitrust authorities have invoked the theory of coordinated effects when attempting to block mergers include the Nestlé-Perrier, Kali and Salz, Gencor-Lenrho, Airtours-First Choice and Sony-BMG cases in the EU jurisdiction, Safeway, Smith-Linpac and Wienerberger-Baggeridge Brick in the United Kingdom and Cruise Ships Hospital Corporation and Arch Coal in the US. See Nestlé-Perrier [1992] OJ L356/1. Case No. IV/M.190, decision dated 22nd July 1992. Kali and Salz Joined Cases C-68/94 and C-30/95, *France and Others v. Commission ('Kali & Salz')*, Judgment of March 31, 1998. Gencor-Lenrho Case No. IV/M. 619 decision dated 24th April 1996. Airtours-First Choice Case No. IV/M.1524 decisoin dated 11nd September 1999. And judgement of the Court of First Instance, T-342/99 dated 6th June 2002. Sony-BMG Case No. Comp/M.3333 decisions dated 19/7/2004 and 3/10/2007. As well as judgement of the Court of First Instance T464/04 (Impala v Commission) which annulled the first commission decision and the judgement of the ECJ which set aside the 'Impala' judgement of the CFI C233/10. Safeway Plc/Tesco/Asda/Sainsbury/Wm Morrison (2003). See http://www.competition-commission.org.uk/inquiries/completed/2003/safeway/index.htm and DS Smith plc/LINPAC Containers Limited (2004) and Wienerberger Finance Service BV/Baggeridge Brick plc (2007). Royal Caribbean Cruises LTD/P&O Princess Cruises Plc and P&O Princess Cruises Plc /Carnival Corporation FTC File no. 0041. Hospital Corp. Of America v. FTC, 807 F.2d 1381, 1386 (7th Cir. 1986). FTC v. Arch Coal, Inc., *329 F. Supp. 2d 109 (D.D.C. 2004)*

number of important directions before taking it to data.[4] Specifically, we allow for asymmetric (firm-specific) discount factors (Harrington(1989)), asymmetric costs (Rothschild (1999), Vasconcelos(2005)), product differentiation (Kuhn(2004)), multi-product firms, competitive fringes and multi-market contact (Bernheim and Whinston (1990)). On the other hand, in our empirical example we do not observe data on capacities so we do not explore asymmetry in capacities in this paper (Lambson (1996), Compte, Jenny and Rey (2002)).

Our research builds on and contributions to three significant literatures. First, we build on the empirical literature on unilateral effects merger simulation. (UEMS)[5] The UEMS literature uses the Bertrand differentiated product model as its benchmark model. and we shall use that underlying model as the stage game of our coordinated effects model.[6]

Second, we build on the empirical literature attempting to evaluate the conduct of firms using game-theoretic pricing models[7] This literature considers prices predicted by collusive and Nash equilibria and evaluates which model better predicts observed market outcomes. Corts (1999) critiqued this empirical literature arguing that the mapping between the empirical test of collusive behavior and the underlying theory of collusion was incomplete. Our paper takes a modest step towards addressing that criticism by taking an actual model of tacit coordination to data.

Third, the (primarily theoretical) literature on tacit coordination under asymmetry. Harrington (1989) considers the role of asymmetric (firm specific) discount factors. Lambson (1994, 1996) studies asymmetric capacities in homogenous product industries and argues that slight asymmetries can reduce the danger of tacit coordination because the firm with greater capacity may have the greatest incentive to undercut its rivals (cheat) and also the greatest ability to punish deviation by others. Compte, Jenny and Rey (2002) explore this logic in greater detail and argue that asymmetric capacities can indeed make collusion more difficult to sustain when aggregate capacity is limited. Vasconcelos (2005) extends Rothschild (1999) and Harrington

[4] Friedman's model makes a number of important and certainly unrealistic assumptions, most notably that firms benefit from complete information. Even so, since Friedman's model forms the basis of analysis in both textbooks and, at least in significant part, law - via the 'Airtours' tests introduced by the Court of First Instance (CFI) in the Airtours judgment in Europe, we consider that empirically exploring the economics of this benchmark model is a useful contribution. Future empirical research will, of course, need to explore coordinated effects merger simulation in incomplete information settings

[5] This literature has evolved over the last two decades following the work of Davidson and Deneckere (1985), Farrell and Shapiro (1990), Baker and Bresnahan (1999), Hausman et al (1994) and Nevo (2000).

[6] In addition to the UEMS literature the model has also been used in models to evaluate vertical integration and restraints. See Brenkers and Verboven (2006), Dubois et al (2006,2008), Villas-Boas (2007) and most recently DG-COMP's decision in the TomTom-TeleAtlas case (2008).

[7] See in particular, Gollop and Roberts (1979), Roberts (1983), Suslow (1986), Bresnahan (1982, 1987), Nevo (2001), Slade (2002) and Salvo (2004).

(1991), and argues that the smallest firms (in his case the highest cost firm) are the most difficult to induce to coordinate while the largest ones are hardest to induce to credibly punish.[8]

Kühn (2004) provides an important theoretical contribution to this literature as the first paper to study differentiated product markets. He finds that the economic forces at work are similar to Vasconcelos (2005) in that, all else equal, small firms may be hardest to incentivise to coordinate while large firms may be hardest to induce to punish credibly, since they will suffer most from severe punishment periods

We follow Kühn (2004) in studying the Bertrand differentiated product game. In some elements he studies a richer context than we do, for example allowing for optimal symmetric punishment schemes following Abreu, Pearce and Stachetti (1990) while we study only grim strategies. He also considers the highest feasible collusive price while we study various forms of perfect coordination, although not always involving all firms in the industry. On the other hand, Kühn makes a number of considerably stronger assumptions than we do, which make his model difficult to use for empirical work. For instance, he considers only symmetric in prices demand systems, discount factors that are common across firms and constant marginal costs that are equal for all (differentiated) products. Such assumptions facilitate theoretical analysis but are restrictive. For example, the result is that under coordination the price per product will be identical for all brands while Nash price asymmetries are heavily constrained. In contrast, we use demand structures, discount rates and marginal costs that may be highly asymmetric and, as a result, firms will frequently choose prices to be highly asymmetric in both Nash and collusive equilibria. Despite the generality of the setting, our theoretical results will allow us to study arbitrary concentrations in product ownership structures. Thus, the context and theoretical results are substantively different, but paper shares a considerable amount of intuition with both Kühn and Vasconcelos. In addition, of course, our primary focus is to provide a full empirical analysis of a real-world case.[9]

In terms of applied papers, Kovacic et al (2007) suggest empirically investigating the profitability of coordination relative to Nash outcomes in order to evaluate the incentives to coordinate. Davis and Sabbatini (2008) note this is one aspect of the incentive to coordinate according to the theory of repeated games and suggest undertaking coordinated effects merger simulation to consider the implications of incentive compatibility constraints; they explore a linear differentiated product demand model numerically. In addition, a number of the theoretical papers discussed above include numeric simulations. For example, Compte, Jenny and Rey (2002)

[8] In essence: (1) a fully collusive agreement might involve allocating a small share, or in extremis, actually involve shutting down an inefficient producer's plant and so, absent side payments, such outcomes will not be incentive compatible for these 'small' firms. And (2) Vasconcelos (2005) agrees with Compte, Jenny and Rey (2002) that in a punishment phase it will be the largest firm which is proportionately most penalized in a punishment period and so who will find harsh punishment strategies hard to find incentive compatible.

[9] Kuhn also provides a duopoly numerical example for a symmetric linear differentiated product demand structure.

calibrate their model with the data from the Nestlé-Perrier case while Kuhn (2004) considers a duopoly model numerically and examines a number of issues including multi-market contact.[10]

The rest of the paper is organized as follows. In Section 2, we describe the network server industry. Section 3 sets the framework for evaluating the incentives to collude. In Section 4, we describe the data, while Section 5 discusses the implementation of the model. Results are presented in Section 6.

2 The Network Server Industry

Servers are computers that provide resources (such as software and files) with other, client, computers on a computer network.[11] Servers are often deployed to run round-the-clock to tackle critical computing tasks such as keeping track of a retail chain's sales, managing a customer database or reconciling stock transactions. Servers range from high-end Unix servers, with numerous processors and multimillion-dollar price tags, to comparatively inexpensive Intel-based machines running a Linux or Microsoft Windows operating system used, for instance, to power small local area networks.

Gartner Group (2008) report that global sales in 2007 were $55bn on a volume of 9million units. Globally, IBM, HP-Compaq, Sun and Dell jointly achieve over 75% of world revenues (see Table 1) with financial corporations, the communications sector and Government respectively responsible for 25%, 14% and 11% of purchases.[12] Network servers have also been at the centre of a number of recent competition policy debates, most notably the European Commission's decision in 2004 against Microsoft.[13]

[10] In addition, Kuhn's duopoly numerical example explores comparative statics for the full equilibrium value set.

[11] For a basic discussion of servers see, for example, Sybex (2001). See Bresnahan and Greenstein (1996) for an economic analysis of the transition from mainframe-based systems to the now dominant 'client-server' computer architecture.

[12] Gartner Group (2007).

[13] In March 2004, the European Commission found Microsoft guilty of violating the EU competition legislation and fined it €497m, the biggest-ever fine in an EU competition case. The EC argued that Microsoft took advantage of its Windows virtual monopoly, unfairly leveraging its dominance over PC operating systems into other markets, especially the market for servers and media player software. In the server market the allegations were that Microsoft was not allowing easy interaction between computer servers using a Windows OS and applications from vendors other than Microsoft itself. Microsoft subsequently appealed DG-COMP's decision to the CFI, who upheld, in large part, the decision in 2008.

Table 1: Market Shares in the World Server Market

Firms	1999 Sales	1999 Units	2001 Sales	2001 Units	2002 Sales	2002 Units	2007 Sales	2007 Units
IBM	28.3	17.3	29.0	15.0	31.1	14.3	31.1	14.5
HP	14.4	12.3	26.6	9.7	25.2	30.1	28.3	29.8
Compaq	14.0	28.0	16.0	23.3	–	–	–	–
Sun	14.0	5.2	15.4	5.8	15.1	6.0	10.8	3.8
Dell	4.1	11.7	6.5	16.1	7.5	18.5	11.4	21.4
Others	25.2	24.9	6.5	30.1	21.1	31.1	13.9	27.1
Market Revenue	USD 48.5 bn		USD 47.0 bn		USD 43.1 bn		USD 54.8 bn	
Market Shipments	3.4 mn units		4.4 mn units		4.6 mn units		8.8 mn units	

Note: Data from Gartner Group (2000, 2002, 2003, 2008). Figures reported under sales and quantity are, respectively, revenue- and quantity-based market shares, illustrating the different presence of the players across market segments. Market shipments report the number of units sold in a given year worldwide.

More firms compete in the low-specification end of the market than at the higher end; low-end servers tend to be less differentiated and based on more standard designs, such as Intel-based platforms. Some smaller players produce high-end products, but usually only in very specific market niches such as technical computing and visualization.

The second half of the 1990s was marked by a series of mergers and acquisitions in the network server industry - see Table 2. HP's acquisition of Compaq was the highest profile. Other acquisitions include those of Sequent (by IBM), Data General (by EMC), DEC and Tandem (each by Compaq) and the Fujitsu-Siemens joint venture.

Market consolidation since the mid-1990s may have resulted from the falling prices of servers. Market observers attribute falling prices to both demand shocks[14] and a process of commoditization.[15] Van Reenen (2006) estimates the yearly quality-adjusted price fall for servers to be of the order of 30% between 1996 and 2001 in the US (and about 22% in Western Europe).[16] Increasing concentration and product commoditization together with significant falls in price can sometimes result in mergers and also, on occasion, firms resorting to attempts at coordination.

[14] The 'Millenium Bug' meant extensive new equipment purchases at the end of the 1990s, suggesting positive demand shocks in the late 1990s. That extra demand was temporary and its removal together with the availability of quality used equipment from bankrupt Internet companies in the early 2000s and uncertainties regarding the economic outlook led to a temporary slowdown in ICT spending and, in particular, on server purchasess. IDC (2002) reports that '[t]he fallout from the dot-com bubble and the "perfect storm" in the IT industry that preceded it caused the worldwide server market to decline by nearly 20% in 2001.'

[15] For example, evidence of competition can be seen in both the high-end server arena, where in early 2001 Sun introduced its newest line at half the price of comparable IBM products and at the lower end of the market, where Dell and Compaq, the top two Windows server sellers, were reportedly involved in a price war to keep market share. Gartner Group (1999) documents that US revenues dropped by 4.3%, whereas shipments grew by 15.9% from 1997Q4 to 1998Q4.

[16] Even before making any adjustments for quality increase, van Reenen (2006) reports price falls of about 10% in the US in the period 1996-2001.

Hewlett Packard (HP) and Compaq formally announced their plans to merge on 4 September 2001 - see Table 2 – in a deal valued at, approximately $25bn.[17] At the time, Compaq ranked first in worldwide server sales. The prevailing view at the time of the merger was that Compaq could help HP with additional market share in both desktops and servers, and enable a 'substantial additional presence' in the service market, given its prior acquisition of DEC.[18,19]

Such a global merger required clearance in a number of jurisdictions and the merger was ultimately cleared in all markets where it underwent scrutiny. The Canadian Competition Bureau, European Commission and FTC respectively cleared the merger in December 2001, early 2002 and March 2002 and the merger cleared that month. Investigators focused on the markets for PCs, servers, PDAs, storage solutions and services.

3 Evaluating the Incentives to Collude

3.1 Qualitative Analysis of Coordinated Effects in the HP-Compaq Merger

Following Chamberlin (1929) and Stigler (1964), economic theory, antitrust merger guidelines and court judgments (in particular Airtours) have argued that whether firms can tacitly sustain coordinated prices depends on a number of factors. Specifically, Stigler (1964) argues that in order to sustain coordination firms must be able to (i) come to an agreement (which can be difficult when products are complex and differentiated), (ii) monitor each others' behaviour (in order to detect undercutting) and, of course, (iii) enforce coordinated behavior collectively by punishing the cheating firms and keep rivals out.

[17] Although the value of the deal on completion was closer to $19bn.
[18] See http://www.hp.com/hpinfo/abouthp/histnfacts/ for details of HP's history.
[19] According to Reuters, ''[b]road hints from HP and a look at market share led industry observers to conclude that HP would use Compaq's well-regarded storage system and its NT servers, low-end network computers that run Microsoft Windows, in stitching together its product line-up. The combined company was also expected to use HP's own high-end Unix servers and Compaq's mainframe-style computer, the (Tandem) Himalaya''
See http://www.reuters.com/article/filmNews/idUSN0245554920020322

Table 2: Key Events in the Network Server Industry 1996-2002

Date		Event
1996	Febuary	Cray acquired by SGI (Silicon Graphics); Packard Bell acquired by NEC, *inter alia*
	July	Sun acquires Cray Business System Division from SGI
1997	June	Tandem acquired by Compaq
	August	AST Research acquired by Samsung
1998	June	DEC (Digital) acquired by Compaq
1999	April	Eckhard Pfeiffer resigns as Compaq's CEO
	June	Joint venture creates Fujitsu Siemens
	August	Data General announced being acquired by EMC
	September	Intergrah exits PC and server business; Sequent acquired by IBM
2000	March	SGI sells Cray to Tera Computer
	April	Tera Computer renamed Cray Inc
2001	September	HP and Compaq announce plans to merge; Moody's downgrades HP debt; Standard & Poors puts HP on negative outlook
	December	HP-Compaq merger cleared in Canada
2002	January	HP-Compaq merger cleared by EU DG Competition
	March	US FTC clears HP-Compaq merger; HP and Compaq shareholders approve merger
	May	Compaq becomes part of HP; New HP-Compaq officially launched

Agreement. The server industry involves a significant number of large players, but with a material competitive fringe of smaller firms. The distribution of brands and market shares varies across time and markets, but participants in our dataset include AST, Acer, Apple, Compaq, Data General, Dell, Digital, Fujitsu, Gateway, HP, Hitachi, IBM, Micron, Mitsubishi, NCR, NEC, Siemens, SGI, Sun, Toshiba, Unisys and VA Linux. Most firms are multi-product firms and so the number of products is substantial. In our dataset, a single geographic market has a maximum of 222 products for sale in a single quarter.[20] At face value, such a large number of differentiated products appear to make the problem of agreeing on a tacitly collusive outcome very difficult in this industry. On the other hand, much of the product heterogeneity may not be greatly valued by customers in the sense that firms may face elastic demands as consumers readily substitute across providers – at least within quality segments.[21]

In this paper, we will suppose that firms can achieve such an agreement, despite the considerable complexity even without the ability to meet to exchange information and/or audit each other's accounts. However, we make this assumption cautiously and we do note that this is potentially an important caveat for our results, as well as an important area for future research. Ideally, we would like to be able to capture the way in which the number of dimensions of an agreement affects the likelihood of collusion but we leave such models for future research, except to note

[20] The maximum number of products observed in our dataset was in Q3 of 2000 in the EU market area.

[21] There is clearly a big quality difference between a high and a low-end server. However, it is less clear that consumers perceive significant differences across providers at a given point in the product quality spectrum.

that the way in which prices are related to product characteristics may provide such a dimension-reducing solution for tacit coordinators (Lancaster, 1966, Gorman, 1955).[22]

Monitoring. One of the Airtours[23] conditions is sufficient market transparency to ensure that all tacitly coordinating oligopolists would become aware 'sufficiently precisely and quickly' of the way in which other members' market conduct is evolving. There is a considerable amount of publicly available market information about servers, since companies such as IDC and Gartner publish detailed quarterly information on shipments (quantities) and revenues by product by geographic region. This appears a considerably greater degree of transparency than was available in the Sony/BMG merger that was the subject of the Impala judgments by the CFI and subsequently by the ECJ.[24] That said, even this information must be treated carefully as at least some information is collated from voluntary reports from companies who can have incentives to either over- or under-report sales.

Industry associations, publications and conferences each also provide opportunities for informal

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communication and/or intelligence gathering. There is also a considerable degree of multi-market contact and firms will often meet in forums, such as standard-setting organizations, as well as sometimes explicitly and legitimately cooperating through joint ventures.[25]

Enforcement. There are two aspects to stability of tacit coordination, internal and external stability which, respectively, apply to the ability of those tacitly colluding to sustain the coordinated outcome(s) and the inability of those not tacitly colluding to gain by disrupting it. In this paper we focus primarily on techniques that can help evaluate these aspects of a tacitly coordinating theory of harm. One of the Airtours conditions[26] was that tacit collusion must be sustainable over time and the CFI noted that some notion of retaliation was "inherent" in this condition.[27] Retaliation

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[22] In the famous case involving GE and Westinghouse in electrical turbines, a published pricing book with formulae were used to help to map product characteristics to prices. Similarly, in the US airline industry the prospect of 'per-mile' pricing was allegedly used as a potential simplifying tool to facilitate a proposed tacitly-collusive arrangement.

[23] Case T-342/99, *Airtours v. Commission*, CFI Judgment of June 6, 2002 (See in particular paragraph 62.) "[F]irst, each member of the dominant oligopoly must have the ability to know how the other members are behaving in order to monitor whether or not they are adopting the common policy. As the Commission specifically acknowledges, it is not enough for each member of the dominant oligopoly to be aware that interdependent market conduct is profitable for all of them but each member must also have a means of knowing whether the other operators are adopting the same strategy and whether they are maintaining it. There must, therefore, be sufficient market transparencyml[(tr)9callye be ,arket tr9s

can take a number of forms, from a reversion to Nash equilibrium to temporary price wars (See Green and Porter (1984) and Porter (1983)'s analysis of the railroad Joint Executive Committee in the 1880s.)

We begin with two observations in relation to the HP/Compaq merger. First, while there are a number of market features that potentially facilitate coordination in the server industry and others hindering it, neither the DOJ/FTC nor DG Competition reported seriously considering a theory of harm that the HP-Compaq merger could lead to coordinated effects. Second, there were no significant objections to the merger from rivals such as Dell, IBM and Sun.[28]

3.2 The Benchmark Model

Our Benchmark model builds on Friedman (1971)[29], and appropriately generalizes it to allow for firm-specific discount factors, differentiated products, asymmetric costs and multi-product firms.

The Stage Game: The UEMS literature often uses the differentiated product Bertrand pricing game[30] and we do the same. Suppose there are J products indexed $j=1,..J$ and $f=1,..,F$ active firms. Denote firm f's products as $\Im_f \subseteq \{1,..,J\}$ and the one-period profits to firm f $\pi_f(p)=\sum_{j\in\Im_f}(p_j-c_j)D_j(p)$ where p_j and c_j are respectively the price and constant marginal cost of product j. The Nash equilibrium $p^{NE}=(p_1^{NE},...,p_J^{NE})$ for the stage game involves each firm choosing their prices to maximize static profits, $\max_{\{p_j|j\in\Im_f\}}\pi_f(p)$ given prices of rivals so that the J first-order conditions for these F (static) problems can be written as:

$$D_k(p)+\sum_{j=1}^{J}\Delta_{jk}*(p_j-c_j)\frac{\partial D_j(p)}{\partial p_k}=0 \quad \text{k=1,..,J}$$

thus inherent in this condition. In this instance, the parties concur that, for a situation of collective dominance to be viable, there must be adequate deterrents to ensure that there is a long-term incentive in not departing from the common policy, which means that each member of the dominant oligopoly must be aware that highly competitive action on its part designed to increase its market share would provoke identical action by the others, so that it would derive no benefit from its initiative (see, to that effect, *Gencor* v *Commission*, paragraph 276);"

[28] Capacity constraints can facilitate or hinder tacit collusion, perhaps resulting from the shortage of silicon (used to manufacture processors), processors themselves, or other components, such as memory and hard disks. However we do not consider such issues further as we do not have data on either inventories or production capacities.In addition, future market growth can be relevant to an evaluation of the likelihood of tacit collusion in an industry. At the end of the period of our dataset, the 'perfect storm' in the IT industry led many observers to believe that the market for servers was expected to shrink. Research from Gartner Group in August 2001 argued that companies had 'overspent $1bn on application server technology since 1998. Their report estimated that an additional $2bn was expected to be overspent in the following two years, and recommended that companies be cautious when acquiring server technology. In: Gencor/Lonrho, for example, market growth was noted as a factor that made collusion more difficult. Although interesting, our focus is elsewhere and so we have left these issues for future research.

[29] The model we present builds upon a vast literature in the last four decades. Notable contributions to the literature of repeated games include Abreu (1986), who studies symmetric Cournot repeated games, and Brock and Scheinkman (1985) and Lambson (1987), who investigate symmetric Bertrand repeated games. Davidson and Deneckere (1984) study how mergers impact collusion using trigger strategies and exogenous market sharing rules, starting from a setting with symmetric capacities and Bertrand competition.

[30] See Werden and Froeb (1994), Berry (1994), Hausman et al (1994), Berry, Levinsohn and Pakes (1995) and Nevo (2002).

where $\Delta_{jk} = 1\{\exists f \in \{1,..,F\} \mid j,k \in \Im_f\}$ is the indicator function taking the value one if products j and k are produced by the same firm and zero otherwise. Define the 'ownership matrix' Δ of dimension J by J with jk[th] element, Δ_{jk}. Changing ownership structure amounts to changing Δ while a perfect cartel's prices are calculated by setting every element of Δ equal to one. Nash and perfectly collusive prices are familiar objects in both the UEMS and conduct literatures. For compactness, we define the Nash equilibrium payoff to firm f as $\pi_f^{NE} \equiv \pi_f(p^{NE})$ and the one-period return to collusion by firm f as $\pi_f^{Coll} \equiv \pi_f(p^{Coll})$ where $p^{Coll} \equiv \arg\max_{\{p_1,..,p_J\}} \sum_{f=1}^{F} \pi_f(p_f, p_{-f})$ where p_f denotes the prices of all firm f products while p_{-f} denotes the prices of products produced by all rival firms.

The Repeated Game: Following Friedman (1971) we study sub-game perfect equilibria (see Selten (1965)) of the repeated game using grim strategies. The literature has subsequently explored a range of possible punishment mechanisms, including 'simple penal codes', as presented in Abreu(1988), and optimal punishment mechanisms à la Abreu, Pearce and Stacchetti (1990).[31]

Define the one-period 'defection' gain to firm f when all other firms are playing collusively as $\pi_f^{Def}(p_{-f}^{Coll}) \equiv \max_{\{p_j \mid j \in \Im_f\}} \pi_f(p_f, p_{-f}^{Coll})$ or, more compactly, π_f^{Def}.

When rivals are playing grim strategies, a defector earns his one period defection payoff and then subsequently receives only his Nash equilibrium profits. The net present value (NPV) of a stream of future profits is: $V_f(\delta_f) = \sum_{t=0}^{\infty} \delta_f^t \pi_{ft}$ so the NPV of anticipated returns to defection today for firm f is: $V_f^{Def} \equiv \pi_f^{Def} + \frac{\delta_f \pi_f^{NE}}{1-\delta_f}$. Notice that we allow for firm-specific discount factors, following for example Lehrer and Pauzner (1999), since investors may require a higher rate of return from particular companies, e.g., late entrants or those following new business models. The NPV payoff

[31] Doing so has a number of advantages. First, Abreu (1988, Theorem 5) shows that simple strategies - a constant sequence of the same static Nash equilibrium - suffice to achieve any feasible subgame-perfect equilibrium payoff. Second, if any deviation is followed by a Nash reversion, the punishments are automatically ensured to be credible (Friedman, 1971). However, Nash reversion is usually not the most severe punishment to defection - this happens only if the Nash equilibrium of the stage game coincides with the minmax payoffs. However, understanding Nash reversion appears likely to be a useful and tractable benchmark, leaving more sophisticated forms of punishment for further research. One view on the topic was recently provided by Professor Jullien recently: "We have this very fancy theory applying the optimal penal code on players , giving the maximum punishment on the deviator, which is a very complex story, because to do that you have to give optimal punishment if he doesn't. I am sceptical on how they would coordinate on that. But to run a case it is sufficient to run the old theory of collusion, which is: firms collude on high price and if one deviates, they go back to Nash." UK Office of Fair Trading and Competition Commission roundtable on Coordinated Effects Theories of Harm in Merger Analysis. Transcript available from: http://www.competition-commission.org.uk/about_us/our_organisation/workstreams/analysis/pdf/roundtable_transcript_final_2.pdf

to collusion today and in all subsequent periods given that rivals continue to collude is $V_f^{Coll} \equiv \frac{\pi_f^{Coll}}{1-\delta_f}$. Hence, firm f has no incentive to deviate from collusive pricing provided that:

$V_f^{Coll} > V_f^{Def}$ or $\frac{\pi_f^{Coll}}{1-\delta_f} > \pi_f^{Def} + \frac{\delta_f \pi_f^{NE}}{1-\delta_f}$ for each firm. These F incentive compatibility constraints (ICCs) play the key role in defining the set of situations in which tacit collusion is individually rational for each firm - and hence feasible. Notice that, under perfect collusion, the only new elements of the ICCs compared to a standard UEMS are (i) the payoffs to defection π_f^{Def} and (ii) the discount factor δ_f. The former depends directly on the nature of the static profit function for each firm and so may be easily calculated using the techniques developed in the UEMS literature.

3.3 Extensions

3.3.1 Introducing a Competitive Fringe: Partial Coalitions

Next we study the effects of a competitive fringe on firms' incentives and ability to cooperate. To that end, suppose that firms can be divided into F_d dominant firms and F_c firms in the competitive fringe, where $F = F_d + F_c$. Define also subsets of their respective products, $\Im_d \subset \{1,..,J\}$ and $\Im_c \subset \{1,..,J\}$. We assume the tacitly collusive profits for a given dominant group of firms are those that result from the Nash equilibrium outcome that would have occurred if, counterfactually, all the members of the coalition had merged.[32] This model allows those not tacitly cooperating to optimally (in a static sense) exploit the market power endowed by the actions of the cartel while the cartel is acting to maximize its joint profits given the actions of the non-cartel members, $\max_{p_d} \sum_{j \in \Im_d} (p_j - c_j) D_j(p_d, p_c)$.

Naturally, all firms' products will be incorporated into the differentiated product demand system we estimate so that the data will determine the extent to which fringe producers in aggregate constrain the ability of a cartel consisting only of the dominant players to raise prices. The extent of the constraint will depend on the degree of product differentiation between the fringe and non-fringe producers.

Intuitively, tacit coordination involving only a subset of firms will leave the dominant firm group worse off since they have less collective flexibility when setting prices compared to a full cartel.

[32] Initially, in considering a fringe model we supposed that firms in the competitive fringe could face a perfectly elastic own-price demand curve for each product, so that the fringe would always price at marginal cost. However, after reflection this approach appears better since it allows the fringe and dominant firms to price according to a Nash equilibrium In particular, we can consider the effects of the fringe attempting to free-ride off the dominant firms high prices.

Since our dominant firm group act collectively as if they had undergone a merger, the fact that intuition is correct follows immediately from the standard result in Bertrand pricing games that mergers between firms producing substitutes are always (at least weakly) profitable. However, it is important to note that it does not immediately follow that each individual member of a cartel is better off when the set of participants in the cartel is increased. In particular, changes in the set of firms who are cooperating will change the cartel's objective function and, as a result in the absence of side payments, individual firms may actively prefer to exclude particular rival interests.

3.3.2 Multi-market Contact

Bernheim and Whinston (1990) argue that if firms interact repeatedly, not only over time but also across some number of markets M>1, be it geographical markets or market niches, tacit collusion can occur. In a context where firms interact over time, multi-market contact essentially pools the ICC of the different markets where firms interact.

Let m=1,..,M denote markets and define $V_{Mf}^{Def} = \sum_{m=1}^{M} V_{mf}^{Def} = \sum_{m=1}^{M} \left(\pi_{mf}^{Def} + \frac{\delta_{mf} \pi_{mf}^{NE}}{1-\delta_{mf}} \right)$ and $V_{Mf}^{Coll} = \sum_{m=1}^{M} V_{mf}^{Coll} = \sum_{m=1}^{M} \left(\frac{\pi_{mf}^{Coll}}{1-\delta_{mf}} \right)$ to be the value functions constructed for firm f as the sums across markets of the value functions to defection and collusion (where the value associated with a market where firm f is not active will be zero.)

The multimarket ICC for collusion for firm f then reads simply: $V_{Mf}^{Coll} > V_{Mf}^{Def}$. Previously we had one constraint for each active firm in each market, in the multi-market context we have just one constraint for each firm that is active in at least one market. Such a formulation makes clear that asymmetry in market activity may, in principle, affect the sustainability of tacitly collusive outcomes as much as cross-firm asymmetry.

3.3.3 Accounting for Antitrust Action

Fourthly, we introduce an antitrust authority.[33] Specifically, we assume there is at least some (albeit perhaps small) probability that firms engaging in tacit coordination could be subject to antitrust

[33] In some jurisdictions, tacit collusion can be prosecuted. This description draws heavily on Whish (2003), in particular the discussion in Chapter 14. In Europe, for example, tacit collusion can potentially be either a violation of Article 81 or Article 82 (and hence their member state equivalents). Under Article 82, tacit collusion could, at least potentially, be prosecuted as an exploitative abuse by a collectively dominant oligopoly (see, in particular, the Commission's *P&I*[33] decision, which contemplated doing so). Article 81 forbids agreements and concerted practice that prevent, restrict of distort competition, where the term 'concerted practice' potentially catches any situation in which firms substitute competition for practical cooperation. The case law in this area includes *Dyestuffs*[33], where the ECJ found that: (i) a concerted practice does not need to have all the elements of a contract, but includes coordination apparent from firm behaviour;, (ii) parallel behaviour itself is not a concerted practice, since there may, for instance, be common cost shocks driving common price movements, but 'it may however amount to strong evidence of such a practice'; (iii) every producer is free to change his prices, taking into account in

action. If so, then those companies should factor both the probability that collusion is detected by the antitrust authorities and the potential to be fined by way of punishment into their value functions. Allowing for coordination detection, the value to coordination of firm f given that rivals continue to collude is:

$$V_f^{Coll}(\delta_f) = \pi_f^{Coll} + \delta_f \left[(1-q) V_f^{Coll}(\delta_f) + q \left(\frac{\pi_f^{NE}(\delta_f)}{1-\delta_f} - \tau \operatorname{Re} v_f^{Coll} \right) \right]$$

where q is the probability of being "caught" by the antitrust authorities and τ is the fraction of revenue $\operatorname{Re} v_f^{Coll}$ of the affected goods and services (so that the fine after being caught is $\tau \operatorname{Re} v_f^{Coll}$.) We assume that if a firm colludes it will manage to do so for one period, while in future periods it will either (with probability 1-q) manage to continue tacitly cooperating or else it will get caught. If it is caught then, following the logic of grim strategies, we assume that competition re-emerges in the industry, so the future periods are characterized by the static Nash equilibrium outcome, while a fine consisting of a fraction of worldwide revenues is paid. Rearranging, the value function associated with collusion can be rewritten as:

$$V_f^{Coll}(\delta_f) = \frac{1}{1-\delta_f(1-q)} \left[\pi_f^{Coll} + \delta_f q \left(\frac{\pi_f^{NE}(\delta_f)}{1-\delta_f} - \tau \operatorname{Re} v_f^{Coll} \right) \right]$$

For the value of defection to firm f, we again assume firms get defection profits for one period and then are neither caught nor punished.[34] Thus the value of defecting remains that of the benchmark model: $V_f^{Def}(\delta_f) = \pi_f^{Def} + \delta_f \left(\frac{\pi_f^{NE}(\delta_f)}{1-\delta_f} \right)$. As before, firm f has no incentive to deviate from collusive pricing provided that $V_f^{Coll}(\delta_f) > V_f^{Def}(\delta_f)$, for $f = 1,..,F$.

4 Data

We use data from the International Data Corporation's (IDC) Quarterly tracker database.[35] It provides data on price, revenue and number of units sold corresponding to every server from the

so doing the present or foreseeable conduct of his competitors; (iv) that 'nevertheless it is contrary to the rules on competition contained in the Treaty for a producer to co-operate with his competitors in any way whatsoever, in order to determine a coordinated course of action relating to a price increase and to ensure its success by prior elimination of all uncertainty as to each others conduct regarding the essential elements of that action, such as the amount, subject matter, date and place of the increases.' (para 118). Thus the case law has evolved to make prosecution of parallel behaviour as a concerted practice difficult, but not impossible, while placing apparently strong restrictions on 'facilitating practices', such as the exchange of information that makes a market more transparent and hence makes tacit coordination easier.

[34] There are a number of potentially interesting alternative formulations. For example, we could allow for defection with leniency applications wherein defection by one player was coincident with 'shopping' ones rivals to the antitrust authorities. We stick to the simplest formulation here.

[35] We use the 7th June 2001 version. For a full description of this database and the recent evolution of the market see IDC (1998, 2000b).

first quarter of 1996 to the first quarter of 2001 in three major regions: USA, Western Europe, Japan.

IDC data cover the population of available products. It gathers revenue and characteristics data from vendors in all the main regions and then cross checks the company totals with global HQs and its own customer surveys. Transaction prices[36] are also estimated on a region-specific, quarterly, model-by-model basis based on discussions with industry participants. These prices take into account the various discounts offered off the list price, as well as trade-ins.

A product in a given region and time period (quarter) is a vendor-family-model-operating system combination. For example Sun Microsystem's (vendor) Ultra-Enterprise (family) 1000HE series (model) running UNIX (operating system). Descriptive statistics are available in an unpublished Appendix available from the authors (see Unpublished Appendix A) There are 33 separately identified vendors most of whom will have only two or three families of models (IBM has the most models and seventeen individual "families").

The IDC data only have basic model characteristics, but van Reenen (2006) collected server characteristics data, matched it into the IDC data and generously made the expanded dataset available to us.[37] The expanded characteristics dataset include the number of rack slots, the chip architecture (RISC, CISC or IA32), motherboard type (e.g., Symmetric Parallel Processing - SMP, Massively Parallel Processing - MPP), the types of operating system used (Windows, UNIX, Netware, OS390/OS400, VMS6 and others - including Linux), vendor indicators and whether the system is rack-optimised.[38]

We have also used stock market and balance sheet data to compute the firms' discount factors. The former are from CRSP and COMPUSTAT Global, while the latter are from COMPUSTAT Global. We also use interest rate data from the Bank of Japan - see Unpublished Appendix B for details and the SMB, HML and momentum factors that Professor French has made available on his web page.[39]

5 The Empirical Model

The building blocks of the model we take to data includes a consumer demand model, a method for estimating firms' discount rates, and we use the standard UEMS technique to 'back out'

[36] Called "street prices" by IDC.
[37] We refer readers to van Reenen (2006) for a discussion of the construction of the dataset.
[38] Rack-mounted servers are designed to fit into nineteen inch racks. They allow multiple machines to be clustered or managed in a single location.
[39] Available from Ken French's webpage at http://mba.tuck.dartmouth.edu/pages/faculty/ken.french/Data_Library/f-f_factors.html

marginal costs from pre-merger prices.[40] In this section we describe the demand model, the identification strategy and also the calculation of discount factors.

5.1 Demand Estimation

We use the random coefficient multinomial logit model due to Berry, Levinsohn and Pakes (1995, BLP hereafter). . (See the previous literature for details: BLP,Berry (1994), Davis (2001), Nevo (2000) and Davis (2006).) The closest empirical demand paper is Ivaldi and Lörincz (2008, henceforth I&L) who estimated a nested multinomial logit (N-MNL) model for servers. Define the conditional indirect utility of consumer i when consuming product j from market (region) m in period (quarter) t as:

$$u_{ijmt} = \sum x_{jmtk}\beta_{ik} + \xi_{jmt} + \varepsilon_{ijmt} \text{ with } i = 1,..,I,\ j = 1,..,J,\ m = 1,..,M \text{ and } t = 1,..,T$$

where x_{jmtk} are observed product characteristics such as price, memory, speed and storage, ξ_{jm} represent unobserved (by the econometrician) product characteristics, assumed observed by all consumers. Following the literature, we decompose the individual coefficients as $\beta_{ik} = \overline{\beta}_k + \sigma_k v_{ki}$ where $\overline{\beta}_k$ is common across individuals and v_{ki} is an individual specific random determinant of the taste for characteristic k. which we assume to be log-normally distributed, $(v_{1i},..,v_{Ki})' \sim LN(0,\Sigma)$. Finally, ε_{ijmt} is a consumer and option-specific idiosyncratic component of preferences, assumed to be a mean zero Type I Extreme Value random variable independent from both the consumer attributes and the product characteristics. The specification of the demand system is completed with the introduction of an outside good, $u_{i0t} = \xi_{0t} + \varepsilon_{i0t}$, since some consumers decide not to buy any server.

This demand specification (i) treats each individual server acquisition as a separate choice (see, for example, Hendel, 1999) and (ii) abstracts away from explicitly modeling inter-temporal substitution (see, for example, Nevo and Hendel (2006) and Gowrisankaran and Rysman (2007) for an alternative approach). On the former, we note that many servers are purchased by businesses and so this is probably a strong assumption. However, since we have no information about the numbers of servers purchased by purchaser, and little indication that such effects ultimately make the aggregate sales of servers 'lumpy' in the way that might concern us, we do not consider our approach unreasonable for our purposes. On the second issue of inter-temporal substitution, again the approach seems not unreasonable in light of the relatively short lives of computers and the fact that the focus of our paper lays not directly in the dynamics on the demand side, although

[40] In what follows we assume pre-merger competition in order to back out the marginal cost estimates. While we could equally have assumed pre-merger collusion before backing out the marginal costs, it is rare for parties to argue they were tacitly coordinating pre-merger in front of antitrust authorities so we suspect this is the more likely variant for casework.

abstracting in this way clearly represents a pragmatic modeling approximation to actual consumer choice behaviour in the industry and future research may relax such assumptions.

I&L study market definition for servers. Instead of re-inventing the wheel, we build on their work and focus our analysis on two particular market segments they identify as separate antitrust markets, namely (1) servers priced below $4,000 and (2) servers priced between $4,001 and $10,000.[41] We refer to these market segments as 0-4 and 4-10, respectively. Doing so provides 5,537 and 8,799 observations, respectively, for analysis.[42] Pre-merger, only the 'big four' firms have market shares above 1% in all three regions in the 0-4 market segment (all of them have more than 5% in fact), and the associated four firm concentration ratios are 51%, 69%, and 61.5% for the US, EU and Japan, respectively. In the 4-10 segment, only five players - those above plus Sun - have market shares above 1% in all three regions. The associated C_4 and C_5 concentration ratios are, respectively, 88%, 82%, 39% and 94%, 86%, 46% for the US, EU and Japan, respectively, so there is considerably greater concentration in the 4-10 segment.

5.2 Identification of the Demand Model

This section describes our identification strategy for demand;following the literature we treat price as endogenous in our demand specification.. A positive first observation is that there is plenty of price variation in the dataset. Prices fell rapidly for servers (at about 15% per annum) and quality improved dramatically during the period covered by the data. We used three types of instruments for price in a given product in a given regional market (US, Japan and Western Europe). First we followed Hausman, Leonard and Zona (1994) using prices of a product in other regions to instrument its price in a given region. We refer to these as "Hausman instruments".

Second we followed BLP ("BLP instruments") and constructed instruments consisting of the number of firms operating in the market, the number of other products of the same firm and the sum of characteristics of products produced by rival firms.

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[41] We note that market research companies informally delineate market segments, also typically using price thresholds. IDC, for instance, defines the volume market segment as the one constituted of servers priced below $25,000, the mid-range segment as the one with servers priced between $25,000 and $500,000, and the high-end segment as the one with servers priced above $ 500,000. In contrast, in a number of competition rulings, including the Compaq-DEC, Fujitsu-Siemens and the HP-Compaq merger cases, DG Competition delineated the server markets on the basis of price bands into separate markets for entry-level servers (below $100,000), medium level servers ($100,000 - $999,999) and large servers (above $1,000,000).

[42] Ivaldi and Lörincz (2008) studied the US, European and Japanese markets separately conducting two versions of the SSNIP test: First, that following the 1997 EU guidelines (EU97) and second, that following the US guidelines from 1984 (US84) test. The former involves asking whether a hypothetical monopolist would have an incentive to increase the prices of the merging firms by 5-10% while the latter involves asking whether the merger would lead to an equilibrium increase in price of between 5 and 10%. The 10% EU97 and 15% US84 tests suggested the same first price threshold at $ 4,000 (the 5% EU97 test suggested $ 3,000 for Japan and the 10% US84 test suggested $ 3,000 for the US). The 10% EU97 test also suggested a second price threshold of $ 10,000 for both the US and Europe, and $ 9,000 for Japan. When it comes to the following price thresholds, the methods disagree markedly: the 10% EU97 test suggests a threshold at $1mil for all three regions, but the 15% US84 test suggests a total of 5 market segments for the US and 6 for both the EU and Japan, but the threshold are markedly different. As a pragmatic solution we decided to consider a market segment with servers priced below $ 4,000 and another with servers priced between $ 4,000 and $ 10,000. These are wider than Ivaldi and Lorincz's results suggest may be strictly necessary so these appear conservative baseline market definition presumptions.

Thirdly, we follow I&L in using Bresnahan, Stern and Trajtenberg (1997, hereafter BST) style instruments. BST suggest using BLP style instruments within a group and/or sub-group of products. In our case, the group refers to processor architecture[43] and sub-group refers to operating systems used.[44] Thus, within market, we calculate the number of (i) other products of the same firm and (ii) other firms in the same group; and (iii) of other products of the same producer in the same group and same subgroup. In addition we used the hybrid BST-Hausman style instruments, namely from the other two regional markets, we calculate the number of rival firms producing products in the same group; and the number of rivals producing products in the same group and same subgroup.

5.3 Demand Estimation Results

Table 3 reports a number of MNL demand specifications under the heading 'standard logit.' In the table, we focus attention on reporting estimating price coefficients[45] since they plan an important role for inferring marginal costs and also during the simulation of unilateral and coordinated effects of mergers. As described above, we examined the use of Hausman instruments, BLP instruments and BST instruments. The results for the 0-4 segment are compared in Panel A of Table 3. First notice that OLS does appear to suffer from endogeneity bias - the OLS estimate of the price coefficient is positive. Second, notice that the estimated price coefficient appears sensitive to the choice of instruments, but neither Hausman nor BST instruments appear to 'solve' the endogeneity problem. In fact, in the 0-4 segment, the BLP instruments are the only ones that perform well, delivering the expected negative and statistically significant price coefficient (β_{price}).

We found that the BST instruments work better in more expensive market segments than in the low-end server market. Intuitively, since low-end servers are fairly standardized, not greatly differentiated, products .the BST instruments, which are based on within group and within sub-

[43] Processor architecture can take on the values: uni-processor (UP), symmetric multi-processor (SMP), or massively parallel processing (MPP).

[44] Linux, Netware, Windows NT, IBM OS400, IBM OS 390, VMS, Unix, Other.

[45] The full parameter estimates for our chosen specifications are reported in an unpublished annex available from the author (Supplementary Tables C.) In particular, all the interaction effects included in the specification are omitted from the table to preserve space and allow the discussion below to focus on the price coefficient estimates which are crucial to the simulation exercise. The full specifications include a full set of interactions between: (i) operating systems (Linux, Netware, Windows NT, Openvms, OS/400, Unix, Other) and regions (EU, US, Japan), (ii) the number of extra racks available in the server (UR) and regions; (iii) extra racks, processor architecture (uniprocessor, symmetric multi-processor, massive multi-parallel processor) or (UP, SMP, MPP) and time fixed effects; (iv) CPU architecture fixed effects (CISC, RISC or IA32 - for Intel 32-bit architecture) interacted with processor architecture (UP, SMP, MPP) and time fixed effects; and (v) operating system interacted with processor architecture interacted with time fixed effects. The variety of interaction terms allow sufficient flexibility to distinguish, for instance, the effects of the number of extra racks (also CPU architecture and operating system) over time for uni-processors and symmetric multi-processors separately; and how the penetration of different firms in different regions evolves over time, for example, the evolution of the Japanese players in Japan (or Fujitsu in Japan and Fujitsu-Siemens in Europe) given the advances of Dell. We explored a range of specifications and since there were a large number of interactions and we wished to avoid an approach which placed too much discretion in our hands so we chose this standard automatic approach. See the Gauss Procedure LinearDep which uses the QR decomposition and can easily be used to automatically check for, and eliminate, approximate linear dependencies in data matrices. See also Besley D, Kuh E, Welsh R. (1980) *Regression Diagnostics* New York: John Wiley and Sons, Inc, 1980.

group data variation tend to collapse and become actually or close to collinear with other included variables.

The final column of the table provides the results from a random coefficient logit (RC-Logit) model of demand with a single log-normal random taste parameter included on the price coefficient.[46] In all cases reported, the first-stage regression of price on the instruments was found to have F-statistics significant at the one percent level. However, the price dispersion coefficient (σ_{price}) was not found to be statistically significant, which suggests that consumer taste heterogeneity is limited for products within the $0-4,000 segment.

Table 3: Results for Alternative Demand Specifications – World Market

	Standard Logit				RC Logit
Panel A: 0-4 Segment	**OLS**	**Hausman**	**BLP**	**BST**	**BLP-LN**
Mean price	0.539	22.138	−13.168	5.547	−12.189
	(3.158)	(3.543)	(−2.262)	(3.216)	(−2.150)
	***	***	**	***	**
Price Dispersion					0.155
					(0.010)
					–
J-statistic p-value	NA	0.241	0.374	0.856	NA
		–	–	–	
100% elastic own price effects?	No	No	Yes	No	Yes
Median own price effects					
EU			−31.290		−30.917
US			−30.163		−29.804
JP			−32.284		−31.921

	Standard Logit				RC Logit
Panel B: 4-10 Segment	**OLS**	**Hausman**	**BLP**	**BST**	**BST-LN**
Mean price	−0.079	−0.135	−1.631	−1.877	−3.979
	(−1.398)	(0.233)	(−1.434)	(−2.029)	(−2.872)
	–	–	–	**	***
Price Dispersion					0.978
					(1.600)
					*
J-statistic p-value	NA	0.084	0.984	0.802	0.601
		*	–	–	–
100% elastic own price effects?	No	No	No	Yes	Yes
Median own price effects					
EU				−10.602	−22.727
US				−9.808	−21.145
JP				−11.159	−23.796

Note: The Table reports estimates of the (mean) price coefficient of logit model, t–statistics (reported within brackets) and the p-value of the price coefficient and the J-statistic of overidentifying restrictions, whenever applicable (NA denotes an exactly identified model). The last column displays results for a random-coefficients logit with BST instruments and Lognormal random draws. The symbols – (resp. *, **, ***) denote not-significant (resp. significant at the 10%, 5%, 1% significance level – note that one-sided t-tests are used for price dispersion). It also reports whether 100% of the own price elasticities were elastic and, whenever this is the case, reports the median own price elasticity.

[46] We tried a considerable number of specifications with random coefficients on other parameters, but as is common in this literature, found the resulting estimates were not well identified.

In the 0-4 segment, the own-price elasticities are within the range between -11 and -40 (-13 to -40 in the US, -17 to -40 in the EU and -11 and -40 in Japan) with a median own-price elasticity of around -31. These results are consistent with low-end servers being close to homogeneous products in the eyes of consumers so that price differences for equivalent products drive large movements in volumes across providers. Similar results are provided by I&L who report an average own-price elasticity of approximately 41. While such elasticities are certainly large, they are the same order of magnitude as those found for cars in Berry, Levinsohn and Pakes (1995)[47]

In the 4-10 segment, the BLP and the BST instruments provide similar results providing negative and statistically significant price coefficients, although, intuitively, we found them to be of smaller magnitude than those of the $0-4,000 segment. Turning to the random coefficient specification in the final column of the table, we found that the random coefficient was statistically significant at the 10% level using a one-tailed test.[48] The elasticities obtained for this market segment were somewhat lower than the $0-4,000, with medians between -21 and -23.

5.4 Estimating Discount Factors

Discount factors are used to calculate the NPV of the profits from each element of the ICC. In an antitrust case, where internal documents are available, one approach would be to use the firms' hurdle rate for the internal rate of return for projects. A second approach relies on asset pricing models (APM's) to infer an appropriate discount rate.[49] We can use approach since our firms are listed. Thirdy, following the theoretical literature, we can calculate the range of discount factors for which collusion can be sustained. We take the second and third approaches and compare the results. First we calculate the weighted average cost of capital (WACC) each firm faces where the cost of debt r_f^d is obtained as the ratio of interest expenses to debt for a given firm[50] and the cost of equity is obtained from an APM.

[47] See the debate between Charlotte Wojczik (2000) and Berry and Pakes (2001) about the reasonableness of price elasticities in the region of -20.(in particular on page 49 of Berry and Pakes (2001).)

[48] Using the normal approximation to the t-distribution, 90% of the distribution lies below 1.282 and 95% lies below 1.645. Since variance parameters can only take on positive numbers, the appropriate test to apply is the one-sided test.

[49] See Berk and DeMarzo (2007) for an introduction to capital budgeting.

[50] Doing so involves calculating a weighted average of the cost of equity and the cost of debt according to their respective participation in the value of the firm: $r_f^* = \frac{D}{V}(1-\gamma)r_f^d + \frac{E}{V}r_f^e$ where $\frac{D}{V}$ and $\frac{E}{V}$ are, respectively, the ratio of debt and equity to the value of the firm, r_f^d is the cost of debt, r_f^e is the cost of equity and γ is the marginal corporate tax rate. We used the book-value of debt for D and the market value of equity (number of shares outstanding times share price) for E, while by definition V=E+D. The cost of debt r_f^d is obtained as the ratio of interest expenses to debt for a given firm, whereas the cost of equity is obtained from an asset pricing model.

Table 4: Quarterly Discount Factors for Firms in the Server Industry

Firm	Disc. Factor	Firm	Disc. Factor	Firm	Disc. Factor
Compaq	0.967	NCR	0.971	Mitsubishi	0.990
Dell	0.957	SGI	0.976	NEC	0.988
Gateway	0.962	Sun	0.959	Toshiba	0.989
HP	0.967	Unisys	0.971	AST	0.950
IBM	0.972	Fujitsu	0.989	Data General	0.950
Micron	0.963	Hitachi	0.989	VA Linux	0.950

Note: The calculation of quarterly discount factors was performed as described in Section 5.4. See Appendix B for a detailed description of the calculations.

Specifically, we followed the finance literature in exploring three specific APM's, namely CAPM, Fama-French (1993, henceforth FF) and Fama-French plus Momentum following Carhart (1997) (FFM). We found that CAPM provided the most reliable results in practice and so have focused the text on the results from that model.[51] CAPM assumes that a stock's systematic risk is measured by its beta, the slope of the regression of excess stock returns on excess market returns: $\left(r_{ft} - r_t\right) = \beta_f\left(r_{Mt} - r_t\right) + e_t$ where r_f is the return of the stock of firm f, r is the risk-free rate, r_M is the return of the market portfolio and e_t is the unexplained part of firm excess stock returns. We (following FF) use the 1-month Treasury Bill for the risk free rate, while the excess return on the market, $\left(r_{Mt} - r_t\right)$, is defined as the value-weighted return on all NYSE, AMEX, and NASDAQ stocks (from CRSP). In practice we used 'long-run' averages for the risk-free rate and the market risk premium. The firm's rate of return on equity can then be estimated using $\hat{r}_{ft}^{e} = r_t + \hat{\beta}_f\left(r_{Mt} - r_t\right)$ Given the cost of debt and equity, we can calculate the WACC r_f^* of firm f, which relates to the discount factor via the expression $\delta_f = \frac{1}{1 + r_f^*}$.

The results are reported in Table 4. Generally, larger firms are expected to have lower betas, thus higher discount factors, due to smaller cost of capital and, by-and-large, this is what happens for US companies. In our case we find that IBM, for instance, has a lower cost of capital than Dell, resulting in discount factors of 0.970 and 0.950, respectively. Dell was, at the time, a fast growing firm with above-average margins in the industry and these were attributed by many to its distinctive business model. It is important to note that the discount rates reported in the table are quarterly since we use quarterly data in the demand model and treat a single quarter as the decision period.

[51] See Appendix B, we compared a number of alternative variable definitions and asset pricing models (namely CAPM, Fama-French and FFM). We carried out a number of checks for robustness and consistency, in the sense that discount factor values were between zero and one.

6 Simulation Results

6.1 Evaluating the Incentives to Collude

We do not have space to report all of our empirical results in full detail. [52] In summary, the static model estimates suggest that individual firms have only limited market power in both the 0-4 and the 4-10 price segments. The reason is simply that the demand estimates suggest reasonably high own-price elasticities of demand. Gross price-cost margins are estimated to be less than 5% in the low-end server ($0-4,000) business and less than 10% in the ($4-10k) segment. Such estimates imply that a theory of harm associated with the unilateral effects of a merger would probably not gain purchase.

First we investigate whether there are incentives to tacitly collude in the network server industry and, in particular, whether such incentives might increase as a result of the HP-Compaq merger. Specifically, we follow Kovacic et al (2006) in examining the difference between competitive and tacitly collusive profits in order to examine the potential incentives to collude. To that end, the profit functions of the stage game for each region and market segment are reported in Table 5 for the 4-10 segment. The column headed $\pi_{pre}^{NE} \rightarrow \pi_{post}^{Coll}$ shows the percentage change in profits that would result should firms be able to coordinate successfully post merger. The results suggest that there is an incentive to cooperate in each market but that the increase in profits would generally be greatest in Japan. The potential profit increase from a pre-merger Nash equilibrium to a post-merger collusive equilibrium are in the range 9-15% in the US, about 13% in the EU, and in the range 20-23% in Japan for the non-merging parties. Notice also that the incentive to coordinate varies substantially across firms.

[52] See supplementary tables C for more detail.

Table 5: Pre- and Post-Merger Static Profits – 4-10 Price Segment

	Pre-Merger			Post-Merger			%Change	
Firm	Coll	Def	Nash	Coll	Def	Nash	$\pi_{pre}^{NE} \rightarrow \pi_{post}^{Coll}$	$\pi_{pre}^{NE} \rightarrow \pi_{post}^{NE}$
Panel A: US								
Compaq	7816	8776	7026					
HP	1388	1696	1258	9204	10219	8304	11.1	0.2
NEC	1	1	1	1	1	1	9.1	0.9
IBM	4383	5141	3964	4383	5142	3992	10.5	0.7
Data Gen	2	3	2	2	3	2	8.9	0.9
Dell	19221	20015	16702	19221	20015	16806	15.0	0.6
NCR	305	405	279	305	405	281	9.3	0.8
Sun	1843	2299	1677	1843	2299	1690	9.8	0.8
Toshiba	31	38	28	31	38	28	10.3	0.7
Panel B: EU								
Compaq	19097	20276	16390					
HP	3878	4633	3440	22976	23946	20002	15.9	0.9
Fujitsu	3220	3964	2868	3220	3964	2964	12.2	3.4
NEC	672	812	596	672	812	613	12.6	2.9
IBM	6571	7689	5814	6571	7689	5999	13.0	3.2
AST	352	418	312	352	418	321	12.6	2.7
Dell	6718	7662	5944	6718	7662	6110	13.0	2.8
Gateway	1	2	1	1	2	1	12.6	2.6
Sun	1261	1597	1124	1261	1597	1162	12.2	3.4
Toshiba	62	75	55	62	75	57	12.6	2.8
Unisys	25	33	23	25	33	23	12.2	3.3
VA Linux	52	62	46	52	62	47	12.6	2.8
Panel C: JP								
Compaq	2390	2870	1962					
HP	1246	1578	1022	3636	4235	2992	21.9	0.3
Fujitsu	3163	3769	2579	3163	3769	2603	22.6	0.9
NEC	3748	4384	3043	3748	4384	3071	23.1	0.9
IBM	1220	1551	1001	1220	1551	1010	21.8	0.9
AST	24	30	20	24	30	20	20.5	0.8
Dell	1272	1548	1052	1272	1548	1060	20.9	0.8
Gateway	1	1	1	1	1	1	21.0	0.8
Hitachi	667	872	547	667	872	552	21.8	0.9
Mitsubishi	414	523	341	414	523	344	21.2	0.8
NCR	13	16	11	13	16	11	20.6	0.8
Sun	1047	1353	858	1047	1358	866	22.0	0.9
Toshiba	976	1242	804	976	1242	811	21.4	0.9

Note: Figures are in thousands 1996 US dollars per quarter. The last two columns report the percentage changes in profits following a merger between HP and Compaq in two situations: (i) from a pre-merger Nash equilibrium to a post-merger collusive equilibrium; and (ii) from a pre-merger to a post-merger Nash equilibrium. The post-merger values for HP report the percentage change of the post-merger values of the merged entity, HP-Compaq, with respect to the combined pre-merger values of HP and Compaq.

We pause to note that, as can be seen in Table 5, the collusive and defection payoffs are independent of market structure – they do not change pre- and post-merger except of course that the merging firms obtain the sum of the pre-merger static payoffs. Notice also that static defection payoffs are always larger than collusive profits. However, the size of the incentive effect is generally modest but potentially interesting. In the 4-10k segment, the size of these effects increase substantially with the static gains to IBM or Dell in the US or EU markets would each be more than $700,000 per quarter per market area. For example, Dell in the US would have a static

payoff under coordination of $19,221,000 per quarter which would rise to $20,015,000 if defecting against the collusive agreement, an increase of just $794,000 per quarter.

6.2 Incentive Compatibility Constraints: The Benchmark Model

Next we examine the IC constraints and in particular how the value function to colluding compares to that associated with the option of defecting in the benchmark model. In later sections we consider how the results change with (i) a competitive fringe, (ii) multi-market contact and (iii) the introduction of an antitrust authority which ensures that tacitly colluding firms run the risk of incurring fines.

To do so, we consider price segments (0-4 and 4-10) and geographic markets (US, EU and Japan) separately. Notably, we find that at discount factors calculated using each firms' estimated WACC, the NPV from collusion is always greater than the NPV of defection. This result implies that the returns to collusion are positive and non-negligible both pre- and post-merger, appears to be robust across all three geographic regions and both market segments.

For example, in the low-end server market segment, the results presented in Table 6 show that the net gains from colluding are significant in all geographic markets. The column headed V(C-D) reports the difference between the value of coordination and defection, the slack in the IC constraint. The results suggest that, prior to the merger, a firm such as Dell would obtain gains of $4.7m pre-merger in the US and almost $1m and $0.5m in Europe and Japan, respectively, whereas the gains of IBM in the three markets would be about $2.5m, $1.1m and $0.7m. On the other hand, by acquiring Compaq, the net gains perceived by HP as a result of collusion increase from $2m to $8.8m. Similar results are presented for the $4-10,000 market segment in Table 7.

While neither collusive nor defection payoffs are affected by the merger, strikingly, the merger is predicted to make the net gains from colluding V(C-D) *smaller* for every firm in every market area. The reason is intuitive – the merger (absent efficiencies) increases Nash equilibrium profits for all players in the market and thus reduces the incentive to collude. This result is a general one. At least to the extent that optimally collusive prices do not change with market structure, neither will each non-merging firms' defection payoffs, and so (ceteris paribus) unilateral effects of a merger will generically tend to narrow the incentive to coordinate. The only potential exceptions to this can appear through the merging firms' incentives to collude. We capture this result in Proposition 1.[53]

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[53] We note that in using terms involving the summation of firms' value functions post merger such as $\sum_{f \in \Im^{merging}} V_f^{collusion}(\Delta^{post})$ we are abusing notation slightly since formally the post merger firm would only have a single value function. This notation should be understood to mean the value associated with the products that were associated with the

Table 6: Pre- and Post-Merger Value Functions – 0-4 Price Segment

	Pre-Merger			Post-Merger			
Firm	**V.Coll**	**V.Def**	**V.(C-D)**	**V.Coll**	**V.Def**	**V.(C-D)**	**%V.(C-D)**
Panel A: US							
Compaq	106869	100043	6826				
HP	31912	29898	2014	138781	129977	8804	-0.4
NEC	2199	2063	136	2199	2066	133	-2.2
IBM	39790	37295	2495	39790	37350	2439	-2.2
AST	4458	4174	285	4458	4180	278	-2.2
Dell	73654	68946	4708	73654	69050	4603	-2.2
Gateway	11738	11017	722	11738	11033	706	-2.2
Hitachi	120	112	8	120	113	7	-2.2
Micron	2813	2639	173	2813	2643	170	-2.2
SGI	60	56	4	60	56	4	-2.2
Sun	3765	3529	236	3765	3534	231	-2.2
Toshiba	3356	3148	208	3356	3152	204	-2.2
Unisys	1368	1281	87	1368	1283	85	-2.2
VA Linux	8563	8023	540	8563	8035	528	-2.2
Panel B: EU							
Compaq	70533	67937	2597				
HP	42705	41184	1521	113238	109239	3999	-2.9
Fujitsu	24634	23765	870	24634	23890	744	-14.4
NEC	2522	2435	87	2522	2448	74	-14.3
IBM	32362	31235	1127	32362	31393	969	-14.0
Data Gen	2	2	0	2	2	0	-14.6
Dell	27958	26973	985	27958	27114	844	-14.3
Gateway	1473	1423	51	1473	1430	44	-14.4
SGI	434	419	15	434	422	13	-14.6
Toshiba	393	379	14	393	381	12	-14.5
VA Linux	111	108	4	111	108	3	-14.4
Panel C: JP							
Compaq	13137	12896	241				
HP	8242	8092	150	21379	20988	391	-0.3
Fujitsu	15001	14725	276	15001	14735	266	-3.7
NEC	17199	16881	318	17199	16893	307	-3.7
IBM	32689	32035	654	32689	32057	632	-3.3
Dell	25466	24976	491	25466	24993	474	-3.4
Gateway	1779	1748	32	1779	1749	31	-3.7
Hitachi	6514	6397	117	6514	6402	112	-3.8
Mitsubishi	2681	2634	48	2681	2635	46	-3.8
Toshiba	5828	5723	105	5828	5727	101	-3.7

Note: Figures are in thousands 1996 US dollars. The post-merger values for HP report the percentage change of the post-merger values of the merged entity, HP-Compaq, with respect to the combined pre-merger values of HP and Compaq.

Proposition 1. In the benchmark model with tacit collusion achieving perfect collusion both before an after the merger, if $\delta_f \quad f \in \Im^{non-merging}$ are fixed, the merger does not generate

products produced pre-merger by firm f. There is of course, no notational risk associated with the term $\sum_{f \in \Im^{merging}} V_f^{collusion}(\Delta^{pre})$. An alternative way to state the result would be to build it directly in terms of the products produced pre- and post-merger. The notation would change slightly but the substance and results would obviously not.

efficiencies and the firms produce weakly substitutable goods, then for any ownership structure before and after the merger Δ^{pre} and Δ^{post} :

1. $V_f^{collusion}(\Delta^{pre}) = V_f^{collusion}(\Delta^{post})$ for all non merging firms $f \in \Im^{non-merging}$
2. $V_f^{Defection}(\Delta^{pre}) \le V_f^{Defection}(\Delta^{post})$ for all non merging firms $f \in \Im^{non-merging}$
3. The incentive of all non-merging firms to tacitly collude weakly narrows post-merger $V_f^{collusion}(\Delta^{pre}) - V_f^{Defection}(\Delta^{pre}) \ge V_f^{collusion}(\Delta^{post}) - V_f^{Defection}(\Delta^{post})$ for all $f \in \Im^{non-merging}$.
4. If $\delta_f^{pre} \ge \delta_f^{post}$ for all $f \in \Im^{merging}$ then the aggregate returns to the merging firms tacitly colluding pre-merger are no smaller than the returns post-merger: $\sum_{f \in \Im^{merging}} V_f^{collusion}(\Delta^{pre}) \ge \sum_{f \in \Im^{merging}} V_f^{collusion}(\Delta^{post})$. If, $\delta_f^{pre} = \delta_f^{post} = \delta$ for all $f \in \Im^{merging}$ then for the merging firms $\sum_{f \in \Im^{merging}} V_f^{collusion}(\Delta^{pre}) = \sum_{f \in \Im^{merging}} V_f^{collusion}(\Delta^{post})$. That is the returns to tacit collusion for the merging parties are greater pre-merger than post-merger provided that post-merger the cost of capital for the enlarged firm is no smaller than for each of its constituent parts.
5. For the merging firms, aggregate static defection payoffs $\sum_{f \in \Im^{merging}} \pi_f(p_{\Delta^{post}}^{Def}) \ge \sum_{f \in \Im^{merging}} \pi_f(p_{\Delta^{pre}}^{Def})$ are no smaller post-merger than pre-merger as are aggregate post-merger Nash equilibrium profits, $\sum_{f \in \Im^{merging}} \pi_f(p_{\Delta^{post}}^{NE}) \ge \sum_{f \in \Im^{merging}} \pi_f(p_{\Delta^{pre}}^{NE})$. If, $\delta_f^{pre} = \delta_f^{post} = \delta$ for all $f \in \Im^{merging}$ then $\sum_{f \in \Im^{merging}} V_f^{Defection}(\Delta^{post}) \ge \sum_{f \in \Im^{merging}} V_f^{Defection}(\Delta^{pre})$.
6. If, $\delta_f^{pre} = \delta_f^{post} = \delta$ for all $f \in \Im^{merging}$ then the net incentive to collude decreases post merger:
$$\sum_{f \in \Im^{merging}} V_f^{collusion}(\Delta^{pre}) - \sum_{f \in \Im^{merging}} V_f^{Defection}(\Delta^{pre}) \ge \sum_{f \in \Im^{merging}} V_f^{collusion}(\Delta^{post}) \sum_{f \in \Im^{merging}} V_f^{Defection}(\Delta^{post}).$$

Proof. See Appendix.

Table 7: Pre- and Post-Merger Value Functions – 4-10 Price Segment

Firm	Pre-Merger V.Coll	Pre-Merger V.Def	Pre-Merger V.(C-D)	Post-Merger V.Coll	Post-Merger V.Def	Post-Merger V.(C-D)	%V.(C-D)
Panel A: US							
Compaq	236851	214658	22193				
HP	42057	38555	3502	278908	253537	25371	-1.3
NEC	16	15	1	16	15	1	-10.8
IBM	132809	121300	11508	132809	122126	10683	-7.1
Data Gen	63	59	4	63	59	4	-11.4
Dell	582458	509446	73011	582458	512476	69982	-4.1
NCR	9238	8577	661	9238	8646	592	-10.4
Sun	55843	51442	4402	55843	51827	4016	-8.7
Toshiba	943	865	78	943	871	73	-7.3
Panel B: EU							
Compaq	578699	500550	78149				
HP	117528	105432	12095	696227	610075	86152	-4.5
Fujitsu	97581	88005	9576	97581	90822	6758	-29.4
NEC	20357	18288	2069	20357	18787	1570	-24.1
IBM	199119	178054	21065	199119	183484	15634	-25.7
AST	10661	9569	1092	10661	9814	847	-22.4
Dell	203585	181848	21737	203585	186697	16888	-22.3
Gateway	39	35	4	39	36	3	-21.9
Sun	38224	34538	3686	38224	35643	2582	-29.9
Toshiba	1889	1696	193	1889	1741	148	-23.4
Unisys	771	697	74	771	719	52	-29.7
VA Linux	1560	1401	159	1560	1438	122	-23.3
Panel C: JP							
Compaq	72434	60362	12072				
HP	37760	31538	6222	110194	91919	18275	-0.1
Fujitsu	95836	79348	16489	95836	80032	15805	-4.1
NEC	113564	93563	20001	113564	94364	19200	-4.0
IBM	36953	30871	6082	36953	31138	5815	-4.4
AST	740	624	116	740	628	112	-3.8
Dell	38548	32370	6179	38548	32615	5934	-3.9
Gateway	27	23	4	27	23	4	-4.0
Hitachi	20209	16906	3303	20209	17055	3155	-4.5
Mitsubishi	12536	10520	2017	12536	10603	1934	-4.1
NCR	388	327	61	388	329	59	-3.8
Sun	31720	26493	5227	31720	26729	4991	-4.5
Toshiba	29577	24793	4785	29577	25000	4577	-4.3

Note: Figures are in thousands 1996 US dollars. The post-merger values for HP report the percentage change of the post-merger values of the merged entity, HP-Compaq, with respect to the combined pre-merger values of HP and Compaq.

Notice that the last result applies to our case, since our cost of capital estimates found that $\delta_{HP} = \delta_{Compaq} = 0.967$. It follows from part 4 of proposition 1 that for the merging parties the aggregate payoff to collusion does not change following the merger, $\sum_{f \in \Im^{merging}} V_f^{collusion}(\Delta^{pre}) = \sum_{f \in \Im^{merging}} V_f^{collusion}(\Delta^{post})$ and this result can be seen in Tables 6 and 7. Similarly, it follows from part 5 of Proposition 1 that the aggregate payoff to defection increases following the merger $\sum_{f \in \Im^{merging}} V_f^{Defection}(\Delta^{post}) \geq \sum_{f \in \Im^{merging}} V_f^{Defection}(\Delta^{pre})$. Again, this result can be seen in

each of the panels in Tables 6 and 7. As a result, part 6 of proposition follows immediately that in this case the net incentive to collude decreases post merger: $\sum_{f\in\Im^{merging}} V_f^{collusion}(\Delta^{pre}) - \sum_{f\in\Im^{merging}} V_f^{Defection}(\Delta^{pre}) \geq \sum_{f\in\Im^{merging}} V_f^{collusion}(\Delta^{post}) \sum_{f\in\Im^{merging}} V_f^{Defection}(\Delta^{post})$. Although the magnitude of the decrease depends on the estimates on the demand side of the model, this result establishes that the direction of the change does not, rather it relies on our empirical finding that $\delta_{HP} = \delta_{Compaq}$.

Proposition 2. Critical Discount Factors. Define the critical discount factor of firm f for a given market structure Δ as: $\delta_f^* = \frac{\pi_f^{Def}(\Delta) - \pi_f^{Coll}(\Delta)}{\pi_f^{Def}(\Delta) - \pi_f^{NE}(\Delta)}$.

1. If we consider perfect collusion both before and after the merger and the merger generates no efficiencies, then $\pi_f^{Coll} = \pi_f^{Coll}(\Delta^{pre}) = \pi_f^{Coll}(\Delta^{post})$ for all $f \in \Im^{non-merging}$, $\pi_f^{Def} = \pi_f^{Def}(\Delta^{pre}) = \pi_f^{Def}(\Delta^{post})$ for all $f \in \Im^{non-merging}$ and, provided the products in the market are weak substitutes, $\pi_f^{NE}(\Delta^{pre}) \leq \pi_f^{NE}(\Delta^{post})$ for all $f \in \Im^{non-merging}$. In that case, critical discount factors for <u>non-merging firms</u> do not decrease following a concentration: $\delta_f^{*\Pr e} = \frac{\pi_f^{Def} - \pi_f^{Coll}}{\pi_f^{Def} - \pi_f^{NE}(\Delta^{pre})} \leq \frac{\pi_f^{Def} - \pi_f^{Coll}}{\pi_f^{Def} - \pi_f^{NE}(\Delta^{post})} = \delta_f^{*Post}$. for all $f \in \Im^{non-merging}$.
2. For the <u>merging</u> parties, we have $\delta_f^{*\Pr e} = \frac{\pi_f^{Def}(\Delta^{\Pr e}) - \pi_f^{Coll}(\Delta^{\Pr e})}{\pi_f^{Def}(\Delta^{\Pr e}) - \pi_f^{NE}(\Delta^{\Pr e})}$ and

$$\delta_f^{*Post} = \frac{\sum_{f\in\Im^{post}} \pi_f^{Def}(\Delta^{Post}) - \sum_{f\in\Im^{post}} \pi_f^{Coll}(\Delta^{Post})}{\sum_{f\in\Im^{post}} \pi_f^{Def}(\Delta^{Post}) - \sum_{f\in\Im^{post}} \pi_f^{NE}(\Delta^{Post})} \text{ for } f \in \Im^{merging}.$$

Next we compare the critical discount factors of the firms operating in a given market. The critical discount factor of a firm, δ_f^*, is the minimum discount factor sustaining collusion and is obtained be equating the value to colluding to the value to defecting, i.e., $\delta_f^* = \frac{\pi_f^{Def} - \pi_f^{Coll}}{\pi_f^{Def} - \pi_f^{NE}}$.

Table 8: Pre- and Post-Merger Critical Discount Factors – 0-4 and 4-10 Price Segments

Firm	0-4 Price Segment			4-10 Price Segment		
	Pre-	Post-	%Change	Pre-	Post	%Change
Panel A: US						
Compaq	0.102			0.549		
HP	0.166	0.080	-52.1	0.697	0.530	-23.9
NEC	0.189	0.193	1.8	0.807	0.821	1.8
IBM	0.158	0.161	1.9	0.644	0.660	2.4
AST	0.196	0.199	1.8	–	–	–
Data Gen	–	–	–	0.817	0.832	1.8
Dell	0.130	0.132	1.9	0.240	0.247	3.2
Gateway	0.179	0.182	1.8	–	–	–
Hitachi	0.192	0.196	1.8	–	–	–
Micron	0.187	0.191	1.8	–	–	–
NCR	–	–	–	0.795	0.810	1.8
SGI	0.198	0.202	1.8	–	–	–
Sun	0.191	0.195	1.8	0.733	0.749	2.1
Toshiba	0.189	0.192	1.8	0.711	0.725	1.9
Unisys	0.197	0.201	1.8	–	–	–
VA Linux	0.189	0.192	1.8	–	–	–
Panel B: EU						
Compaq	0.198			0.303		
HP	0.270	0.114	-57.6	0.632	0.246	-61.1
Fujitsu	0.320	0.354	10.6	0.679	0.744	9.6
NEC	0.364	0.399	9.8	0.650	0.706	8.5
IBM	0.291	0.322	10.8	0.596	0.662	10.9
AST	–	–	–	0.626	0.680	8.5
Data Gen	0.380	0.417	9.7	–	–	–
Dell	0.310	0.343	10.7	0.549	0.608	10.6
Gateway	0.371	0.408	9.7	0.623	0.676	8.4
SGI	0.379	0.415	9.7	–	–	–
Sun	–	–	–	0.710	0.771	8.6
Toshiba	0.375	0.411	9.7	0.646	0.701	8.4
Unisys	–	–	–	0.724	0.782	8.0
VA Linux	0.372	0.408	9.7	0.646	0.700	8.4
Panel C: JP						
Compaq	0.522			0.528		
HP	0.530	0.481	-9.2	0.597	0.482	-19.3
Fujitsu	0.527	0.536	1.7	0.510	0.520	2.0
NEC	0.519	0.528	1.7	0.475	0.484	2.0
IBM	0.408	0.416	1.9	0.602	0.612	1.6
AST	–	–	–	0.578	0.587	1.5
Dell	0.455	0.463	1.8	0.556	0.565	1.7
Gateway	0.581	0.589	1.5	0.607	0.616	1.5
Hitachi	0.573	0.582	1.5	0.632	0.642	1.5
Mitsubishi	0.590	0.599	1.5	0.601	0.610	1.5
NCR	–	–	–	0.586	0.595	1.5
Sun	–	–	–	0.618	0.629	1.6
Toshiba	0.563	0.572	1.5	0.606	0.616	1.6

Table 8 reports the critical discount factors, those above which collusion is incentive-compatible. We find that they are substantially lower than those estimated as each firms WACC, and the difference is starkest in the 0-4 price segment while the two are closest in the $4-10,000 segment where threshold values are above 0.8 in the US and slightly below that in the other markets. Applying the results in Proposition 2, part (1), notice that the critical discount factor for **non-merging** firms always increases from pre-merger to post-merger levels. This move is consistent

with the merger making it harder for non-merging firms to tacitly coordinate. There is no analogous general result for merging firms, and indeed, one interesting feature of Table 8 is that the critical discount factors for the merging parties fall after the merger. In that sense, the merging parties find that collusion is 'easier' to sustain post-merger than pre-merger which stands in contrast to the non-merging parties who each find that their critical discount factors increase as a result of the merger. The reason for the latter effect is that non-merging firms static collusive and defection payoffs do not change pre- and post-merger, while their Nash equilibrium payoffs unambiguously rise.

6.3 Multi-market Contact

The effect of multimarket contact essentially amplifies the results of the standard model. Given non-binding incentive-compatibility constraints, their aggregation across geographical markets puts an increased wedge between the value of tacitly colluding when compared to the value of defecting. Table 9 shows that for the 0-4 market the pre-merger gains to tacitly colluding are in excess of $9.6m in present value terms for Compaq, $3.6m for HP (making a total of $13.3m), $6m for Dell and $4.2m for IBM, whereas the corresponding post-merger values are marginally lower at $13.2m for HP-Compaq while Dell and IBM's incentives similarly decrease by fairly small amounts. For the same reasons as in the Benchmark case, the net gains from colluding decreased for all non-merging parties (see %V(C-D).)

In the 4-10 market segment, the gains from coordination both pre- and post-merger are more substantial in both absolute and relative terms. For example, the results suggest that a player such as Dell would gain almost $93m post-merger by sustaining the collusive outcome. The gains from Fujitsu and NEC are also noticeable, especially when compared to IBM's post-merger $32m, and come mostly from their strong position in the Japanese market. However, as in the benchmark case, all non-merging firms see a decrease in their relative incentive to collude post merger relative to the situation pre-merger. In our example, the merging parties also see a decrease in their relative payoff to collusion following the merger. An analysis of the critical discount factors shows qualitatively similar results as those obtained for the single market contact case (see the discussion of Table 8.) Finally, for completeness, we note that unreported results obtained for the case aggregating across both geographical markets and market niches also provides similar results.[54]

[54] See Supplementary Tables C for further results on critical discount factors.

Table 9: Multimarket Value Functions

Firm	Pre-Merger			Post-Merger			
	V.Coll	V.Def	V.(C-D)	V.Coll	V.Def	V.(C-D)	%V.(C-D)
Panel A: 0-4 Price Segment							
Compaq	190539	180875	9664				
HP	82859	79173	3685	273398	260204	13193	-1.2
Fujitsu	39635	38490	1145	39635	38625	1009	-11.8
NEC	21920	21379	541	21920	21407	514	-5.0
IBM	104840	100565	4276	104840	100800	4040	-5.5
AST	4458	4174	284	4458	4180	278	-2.2
Data Gen	2	2	0	2	2	0	-14.6
Dell	127078	120894	6184	127078	121157	5921	-4.2
Gateway	14991	14187	805	14991	14211	780	-3.0
Hitachi	6634	6510	124	6634	6514	119	-3.7
Micron	2813	2639	173	2813	2643	170	-2.2
Mitsubishi	2681	2634	48	2681	2635	46	-3.8
SGI	494	476	19	494	478	17	-12.1
Sun	3765	3529	236	3765	3534	231	-2.2
Toshiba	9576	9250	327	9576	9260	316	-3.2
Unisys	1368	1281	87	1368	1283	85	-2.2
VA Linux	8674	8130	544	8674	8143	532	-2.3
Panel B: 4-10 Price Segment							
Compaq	887984	775570	112414				
HP	197344	175525	21820	1085328	955530	129798	-3.3
Fujitsu	193417	167352	26065	193417	170854	22563	-13.4
NEC	133937	111866	22072	133937	113166	20771	-5.8
IBM	368880	330225	38655	368880	336748	32132	-16.8
AST	11401	10193	1208	11401	10442	959	-20.6
Data Gen	63	59	4	63	59	4	-11.4
Dell	824591	723664	100927	824591	731787	92803	-8.0
Gateway	66	57	9	66	58	8	-12.6
Hitachi	20209	16906	3303	20209	17055	3155	-4.4
Mitsubishi	12536	10520	2017	12536	10603	1934	-4.1
NCR	9626	8904	722	9626	8975	650	-9.8
Sun	125787	112472	13314	125787	114198	11589	-12.9
Toshiba	32409	27354	5056	32409	27612	4797	-5.1
Unisys	771	697	74	771	719	52	-29.7
VA Linux	1560	1401	159	1560	1438	122	-23.3

Note: Figures are in thousands 1996 US dollars. The post-merger values for HP report the percentage change of the post-merger values of the merged entity, HP-Compaq, with respect to the combined pre-merger values of HP and Compaq.

6.4 The Competitive Fringe Model

Next we report the results of the competitive fringe model. We examined a number of alternative sets of dominant firms, including four (Compaq, HP, Dell, IBM), five (plus Sun) or six (plus Fujitsu-Siemens) dominant firms. In fact, we obtained qualitatively similar results in each case, so we only report results for the competitive fringe (CF hereafter) model with four dominant firms; see Table 10.

Table 10: Competitive Fringe Model Value Functions – 0-4 and 4-10 Price Segments

	Pre-Merger			Post-Merger			
Firm	V.Coll	V.Def	V.(C-D)	V.Coll	V.Def	V.(C-D)	%V.(C-D)
Panel A: 0-4 Price Segment							
Region: US							
Compaq	100194	99804	390				
HP	29902	29823	79	130096	129670	426	-0.4
Dell	52951	52785	165	52951	52865	86	-1.9
IBM	43967	43844	122	43967	43910	56	-1.9
Region: EU							
Compaq	68364	67853	511				
HP	41380	41131	249	109744	109111	632	-16.8
Dell	20786	20676	110	20786	20783	3	-97.5
IBM	36978	36763	215	36978	36950	28	-87.1
Region: JP							
Compaq	12931	12882	48				
HP	8113	8083	30	21044	20968	76	-2.8
Dell	19237	19151	86	19237	19164	73	-15.0
IBM	37921	37720	202	37921	37745	176	-12.7
Region: US/EU/JP							
Compaq	181489	180540	949				
HP	79395	79037	358	260884	259749	1134	-13.2
Dell	92973	92612	361	92973	92811	162	-55.2
IBM	118866	118327	539	118866	118606	260	-51.7
Panel B: 4-10 Price Segment							
Region: US							
Compaq	221678	213785	7893				
HP	39304	38352	952	260982	252540	8442	-4.6
Dell	418323	390127	28196	418323	392420	25903	-8.1
IBM	146204	142172	4031	146204	143147	3057	-24.2
Region: EU							
Compaq	536485	498470	38015				
HP	108938	104794	4144	645423	607656	37767	-10.4
Dell	145295	139037	6258	145295	142692	2603	-58.4
IBM	217368	208487	8881	217368	214871	2497	-71.9
Region: JP							
Compaq	60341	59501	840				
HP	31356	31011	345	91697	90675	1021	-13.8
Dell	24767	24489	278	24767	24663	103	-62.8
IBM	36163	35764	399	36163	36061	102	-74.5
Region: US/EU/JP							
Compaq	818504	771756	46748				
HP	179598	174157	5442	998102	950871	47231	-9.5
Dell	588384	553652	34732	588384	559775	28609	-17.6
IBM	399734	386423	13311	399734	394079	5656	-57.5

In examining the results reported in Table 10, it is useful to compare them with those in Tables 6 and 7 for the full set of firms coordinating. For example, in the US \$0-4,000 segment, Dell's NPV of pre-merger cooperative profits drop from \$73,654,000 (see Table 6) to \$52,951,000 (see Table 10). In general, a smaller dominant group should be expected to support only lower coordinated prices and hence achieve lower profits and indeed Compaq and HP have a similar experience to Dell in that their profits from full coordination (all firms) are higher than with only a partial

coalition. However, notice that not all firms are worse off with the smaller dominant firm group. IBM, for example, actually does better with the smaller coordinating group - its share of coordinated profits in the US $0-4,000 rise from $39.8m (see Table 6) to $44m. (see Table 10). Intuitively, if some tacitly coordinating members are heavily constrained by outsiders while others are not, then the smaller group may find it optimal to sacrifice disproportionately the profits of the most constrained firms. In our case, this appears to be the case, to IBM's benefit.

Table 11: Comparison of Critical Discount Factors for the 0-4,000 Price Segment for Alternative Market Configurations

Firms	I (Table 4) CAPM Discount Factor	II (Table 8) Benchmark Model			III Multimarket Contact	IV Competitive Fringe			V (Table 11) Multimarket and Competitive Fringe
		US	EU	JP	US/EU/JP	US	EU	JP	US/EU/JP
Compaq	0.967	0.102	0.198	0.522	0.149	0.360	0.363	0.630	0.385
HP	0.967	0.166	0.270	0.530	0.236	0.652	0.532	0.654	0.577
Dell	0.957	0.130	0.310	0.291	0.202	0.510	0.611	0.484	0.541
IBM	0.972	0.158	0.291	0.408	0.245	0.623	0.573	0.379	0.534
		Which firms tacitly collude according to the model?							
		All			All	'Big Four'			'Big Four'

Note: The market configuration referred to in Column II is such that all firms tacitly collude, meaning 14, 11 and 10 firms in the US, European and Japanese market, respectively (see Table 6 for the corresponding value functions). The market configuration referred to in Column III is such that 17 firms tacitly collude (see Table 9 - Panel A, for the corresponding value functions). Finally, the market configurations referred to in Columns IV-V is such that only the 'Big Four' firms (Compaq, HP, Dell and IBM) tacitly collude (see Table 10 for the corresponding value functions).

Next we introduce both multi-market contact and a competitive fringe. Doing so involves incorporating two forces acting, generally, in different directions. In the main, multi-market contact helps cooperation while a competitive fringe generally makes it more difficult. In our empirical example, the net impact is that firms retain the ability to coordinate both pre- and post-merger (see Table 10). We obtained similar results when allowing for multi-market contact across the price segments as well as across regions.

Table 11 collects and compares the estimates of (pre-merger) critical discount factors across models in the 0-$4,000 price segment. Interestingly, multi-market contact has distinctly ambiguous effects empirically across jurisdictions. For instance, the critical value for Compaq under multi-market contact (see column III of Table 11) is 0.149 while in the benchmark model (column II) the critical values, which naturally vary by jurisdiction, is lower at 0.102 in the US but higher at 0.198 in the EU and considerably higher at 0.522 in Japan. Thus multimarket contact would ease

the difficulty of coordination in Japan, but it would make it actively more difficult in the US. This empirical result is intuitive - pooling the IC constraints effectively means that an 'averaging' of critical values occurs across markets. In the model with both multimarket contact and a competitive fringe, column V shows that multi-market contact does not fully offset the disadvantages of the competitive fringe for coordination so that critical discount factors remain substantially above those for the benchmark model.

6.5 Smaller Partial Coalitions

Next we consider the 3 firm cooperative groups formed by Compaq, HP and IBM and, in particular, the effect of the HP-Compaq merger on such a small group of coordinating firms. Table 12 reports the results. We find that while pre-merger, the gains to cooperating are positive for all firms in all jurisdictions and market segments (see columns headed Pre-Merger), post-merger cooperation is, in contrast, not always incentive-compatible. For example, in the US and EU in the $0-4,000 price segment the model suggests that IBM would not be willing to coordinate,[55] Thus, the model suggests the HP-Compaq merger will make tacit cooperation harder to sustain. The results with multimarket contact show that it is not to be enough to re-introduce the concerns around competition in this instance. Of course, as we have already noted, the test being applied throughout this paper is whether 'perfect' tacit coordination among cooperating firms can be sustained. Allowing for imperfect cooperation, would mean that while the coordinating group doesn't succeed in maximizing their collective profits, they may nonetheless be able to find a set of prices at which IBM and HP-Compaq are willing to coordinate. Davis and Sabbatini (2008) study such situations numerically and find, intuitively, that the large firm will often be willing to 'give-up' some collusive profits to make it worthwhile for unwilling partner(s) to cooperate. Doing so typically involves selecting prices which are above the perfectly collusive prices for the unwilling partner and below the collusive prices for the 'leader' in the coordinating group. We pause to note that such predictions are, at least in principle, testable using conventional techniques from the empirical identification of conduct literature.

[55]Similarly, the EU and Japan in the 4-10 market segment (while the incentive to cooperate in the US is predicted to remain positive, but drop by 75% as a result of the merger.)

Table 12: Value Functions for the Tacit Coordination Among Compaq, HP and IBM

Firm	Pre-Merger V.Coll	Pre-Merger V.Def	Pre-Merger V.(C-D)	Post-Merger V.Coll	Post-Merger V.Def	Post-Merger V.(C-D)	%V.(C-D)
Panel A: 0-4 MarketSegment							
Region: US							
Compaq	99957	99791	166				
HP	29831	29818	13	129788	129654	133	-25.7
IBM	43862	43838	24	43862	43904	-42	
Region: EU							
Compaq	68137	67841	296				
HP	41243	41122	121	109380	109096	284	-31.9
IBM	36855	36757	99	36855	36944	-89	
Region: JP							
Compaq	12887	12879	8				
HP	8086	8081	4	20973	20963	10	-22.1
IBM	37794	37713	81	37794	37739	55	-31.7
US/EU/JP Markets							
Compaq	180981	180510	471				
HP	79160	79022	138	260141	259714	427	-29.9
IBM	118512	118308	204	118512	118587	-75	
Panel B: 4-10 Market Segment							
Region: US							
Compaq	216202	213050	3152				
HP	38398	38163	236	254600	251743	2858	-15.7
IBM	142961	141661	1301	142961	142638	323	-75.2
Region: EU							
Compaq	519135	497591	21545				
HP	105411	104515	896	624546	606829	17717	-21.1
IBM	210292	208043	2249	210292	214476	-4184	
Region: JP							
Compaq	60042	59482	560				
HP	31203	30999	204	91245	90698	547	-28.4
IBM	35986	35752	234	35986	36069	-82	
US/EU/JP Markets							
Compaq	795380	770122	25258				
HP	175012	173677	1335	970391	949270	21121	-20.6
IBM	389240	385455	3785	389240	393183	-3943	
Panel C: Multimarket Contact Across Geographical Markets and Price Segments							
Compaq	976361	950632	25728				
HP	254172	252698	1473	1230532	1208984	21549	-20.8
IBM	430819	427514	3305	430819	434273	-3454	

Note: Figures are in thousands 1996 US dollars. The post-merger values for HP report the percentage change of the post-merger values of the merged entity, HP-Compaq, with respect to the combined pre-merger values of HP and Compaq.

6.6 Side Payments and "Balanced Temptation"

Next, following Sabattini (2006), recall that Friedman (1971) introduced a notion of the "balanced temptation" equilibrium as a mechanism for achieving a cooperative outcome in a non-cooperative setting. The idea is that all firms would, in a particular sense, be equally tempted to defect from the tacitly cooperating group of firms, specifically, that they would have the same

discount factor.[56] Friedman argued that this was the lowest discount factor capable of sustaining cooperation on the Pareto frontier of the set of feasible profits of the industry and that this was a less extreme solution than that suggested by the maximization of industry profits.

One way to implement this equilibrium is to allow for side payments across firms up to the point that discount factors are uniform, so that firms which benefit from a collusive solution are allowed to make transfers to others and in so doing will generate incentives for other firms to take part in the collusive agreement. In particular, side payments may make cooperation incentive-compatible for every player, thus making the collusive agreement more stable. Specifically, for any given $\delta = \delta_1 = .. = \delta_F$ we can calculate, the net side payments λ_f f=1,..,F required for each firm to sustain cooperation: $\delta_f = \frac{\pi_f^{Def}(\Delta) - \pi_f^{Coll}(\Delta) - \lambda_f}{\pi_f^{Def}(\Delta) - \pi_f^{NE}(\Delta)}$. Since side-payments must add to zero, $\sum_{f=1}^{F} \lambda_f = 0$ we can determine both δ and the set of λ_f's. As always, we can consider both full and partial coalitions.

Table 13 reports the results and shows that the side payments required are generally quite small, less than $300,000 per quarter in each of the markets and market segments we considered. Mechanisms, such as purchases of goods from rival companies, could potentially be used to achieve side payments of this kind of magnitude. The form of the transfers required are themselves interesting. In Panel A, transfers are each from Compaq to its smaller rivals (pre-merger; and from HP-Compaq post merger) as the small firms must be induced to cooperate. The one interesting exception to this pattern is in Japan in the 4-10 market segment, where Dell is found to need to compensate HP and HP-Compaq.

[56] In Friedman's words (pp. 9), "the ratio of short term gain (…)to the loss per period of having done so is identical for all players".

Table 13: Side Payments to Sustain Uniform Critical Discount Factors Across Coordinating Firms

	0-4 Market Segment		4-10 Market Segment	
Firm	Pre-Merger	Post-Merger	Pre-Merger	Post-Merger
Panel A: Compaq-HP-IBM Tacit Coordination				
Region: US				
Compaq	-1.9		-25.0	
HP	0.9	-1.9	12.5	-25.0
IBM	0.9	1.9	12.5	25.0
Region: EU				
Compaq	-2.4		-248.6	
HP	1.0	-4.0	108.1	-229.4
IBM	1.3	4.0	140.5	229.4
Region: JP				
Compaq	0.4		-4.1	0.0
HP	0.3	0.4	2.0	-6.3
IBM	-0.8	-0.4	2.1	6.3
US/EU/JP Markets				
Compaq	-3.8		-277.1	
HP	2.3	-5.5	123.0	-259.8
IBM	1.5	5.5	154.1	259.8
Panel B: Compaq-HP-Dell Tacit Coordination				
Region: US				
Compaq	-1.8		165.9	
HP	1.3	-2.3	66.1	181.8
Dell	0.6	2.3	-232.0	-181.8
Region: EU				
Compaq	-2.4		-214.8	
HP	0.9	-3.9	108.4	-184.8
Dell	1.5	3.9	106.4	184.8
Region: JP				
Compaq	0.2		-3.5	
HP	0.2	0.1	2.2	-5.2
Dell	-0.4	-0.1	1.4	5.2
US/EU/JP Markets				
Compaq	-4.1		-53.2	
HP	2.4	-6.1	176.3	-10.2
Dell	1.7	6.1	-123.1	10.2

Note: Figures are in thousands 1996 US dollars per quarter.

6.7 Accounting for Antitrust Action

Next we examine the possibility of punishment for participating in tacitly cooperative agreements following the IC constraint developed in Section 3.3.3 above. The expanded IC constraint is:

$$\frac{1}{1-\delta_f(1-q)}\left[\pi_f^{Coll} + \delta_f q\left(\frac{\pi_f^{NE}(\delta_f)}{1-\delta_f} + \tau \operatorname{Re} v_f^{Coll}\right)\right] > \pi_f^{Def} + \delta_f\left(\frac{\pi_f^{NE}(\delta_f)}{1-\delta_f}\right)$$

Table 14: Value Functions Accounting for Enforcement in the Competitive Fringe Model

Firm	Pre-Merger V.Coll	Pre-Merger V.Def	Pre-Merger V.(C-D)	Post-Merger V.Coll	Post-Merger V.Def	Post-Merger V.(C-D)
			US Jurisdiction			
0-4 Price Segment						
Compaq	95850	99804	-3954			
HP	27907	29823	-1917	123768	129670	-5902
Dell	50262	52786	-2524	50277	52865	-2588
IBM	41468	43844	-2376	41485	43910	-2425
4-10 Price Segment						
Compaq	210159	213785	-3626			
HP	36807	38352	-1545	247098	252540	-5442
Dell	406820	390127	16693	407256	392420	14836
IBM	140175	142172	-1997	140433	143147	-2713
Multimarket Contact: 0-4 and 4-10 Segments						
Compaq	306010	313589	-7580			
HP	64713	68175	-3462	370866	382210	-11343
Dell	457081	442912	14170	457533	445285	12248
IBM	181643	186017	-4374	181919	187057	-5138
			EU Jurisdiction			
0-4 Price Segment						
Compaq	63991	67853	-3862			
HP	39344	41131	-1787	103368	109111	-5744
Dell	18107	20676	-2569	18127	20783	-2655
IBM	34454	36763	-2309	34504	36950	-2447
4-10 Price Segment						
Compaq	517930	498470	19460			
HP	105643	104794	849	624729	607656	17073
Dell	137949	139037	-1087	138645	142692	-4047
IBM	210026	208487	1538	211718	214871	-3154
Multimarket Contact: 0-4 and 4-10 Segments						
Compaq	581921	566323	15598			
HP	144986	145924	-938	728097	716768	11329
Dell	156056	159712	-3656	156772	163475	-6702
IBM	244479	245250	-771	246221	251821	-5600
			JP Jurisdiction			
0-4 Price Segment						
Compaq	8668	12882	-4215			
HP	6130	8083	-1953	14799	20968	-6169
Dell	16564	19151	-2587	16566	19164	-2597
IBM	35402	37720	-2317	35409	37745	-2336
4-10 Price Segment						
Compaq	50609	59501	-8892			
HP	29041	31011	-1970	79693	90675	-10982
Dell	18650	24489	-5839	18683	24663	-5980
IBM	31217	35764	-4547	31296	36061	-4765
Multimarket Contact: 0-4 and 4-10 Segments						
Compaq	59277	72383	-13107			
HP	35171	39094	-3923	94492	111643	-17151
Dell	35214	43640	-8426	35250	43827	-8577
IBM	66619	73483	-6864	66705	73806	-7101

We set τ=0.1 since evidence on fine levels in the three geographic regions considered suggested that would be broadly appropriate.[57] Calibrating a reasonable value for q, the probability that a

[57] Specifically, in the EU, the maximum fine for each firm is 10% of its total turnover in the preceding business year. See Regulation EC No 1/2003 at http://europa.eu/scadplus/leg/en/lvb/l26092.htm. In the US, the 2007 Federal Sentencing Guidelines state that for an organization, the fine shall be 20% of the volume of affected commerce. See http://www.ussc.gov/2007guid/2r1_1.html In Japan, the maximum fine by the Japanese Fair Trade Commission is 10% of the sales value of the relevant goods or services See the amendments of the Japanese Antimonopoly Act introduced in 2005 at

tacitly cooperating firm is caught in a given quarter given that it was not caught before, is difficult, both for us and, no doubt, for firms considering such coordination. One admittedly imperfect approach to the problem is to use the results from Levenstein and Suslow (2006), whose survey reports that the average cartel lasts for between 3.7 and 7.5 years (11 and 30 quarters, respectively). For each figure, we compute the corresponding parameter of a geometric distribution (the discrete counterpart of the exponential distribution), leading to a probability of a cartel being caught at a given quarter (given that it was not caught before) of 0.091 and 0.033, respectively. Since we expect this particular type of cartel to be difficult to detect and difficult to take enforcement action against, in what follows we began by using the smaller of these two numbers but primarily, for reasons we explain below, we report the results using q =0.01.

We compute the incentive-compatibility constraints for each jurisdiction (geographic market - US, EU and JP) separately in the case where the dominant firm group consists of Compaq, HP, Dell and IBM. The results in Table 14 suggest tacit cooperation does not pay-off for any of the large firms in the 0-4 price segment in any jurisdiction. The same is true in Japan in the 4-10 price segment, however it does pay for some of the firms to cooperate in that segment (Dell in the US, pre- and post-merger; HP, Compaq and IBM pre-merger and HP-Compaq post-merger in the EU).

The results, while based on strong assumptions, do indicate that even if the probability of cartel detection and prosecution is small, if authorities use the full potential magnitude of their powers to fine, then such punishments can play a role in inhibiting collusive behaviour. Of course, whether incentives are, in practice, affected sufficiently to deter tacit cooperation will depend both on firms' expectations of the probability of successful enforcement action and also on the details of the industry being considered. Specifically, the deterrent effect of a fining regime based on maximum fines involving a fraction of worldwide revenues for an industry will depend on the relative scale of annual revenues and the NPV of profits. In the server market, our demand estimates suggest that the industry has large revenues but, even under cooperation, relatively high own-price elasticities of demand and hence low price-cost margins. Such circumstances are likely to be favourable for this structure of fines to work to deter collusive behaviour.

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http://www.icn-kyoto.org/documents/materials/Fines%20report%20-%20FINAL.pdf and http://www.jftc.go.jp/e-page/index.html for more information..In practice, fine levels can be smaller than these figures. First, in the EU and Japan they are maximums and second jurisdictions operate leniency and other programs which mean that 'discounts' may be available.

Table 15: Rejections of the Null Hypothesis of Equality Between Model-Implied and CAPM Betas Against the Two-Sided Alternative

	Pre-Merger		Post-Merger	
	0-4 Segment	**4-10 Segment**	**0-4 Segment**	**4-10 Segment**
Standard model				
US	12/12	6/8	11/11	5/7
EU	9/9	10/10	5/8	7/9
JP	7/10	11/12	7/9	10/11
Standard model + MM contact (aggregation across regions)				
	14/14	11/13	13/13	11/12
Std model + MM contact (aggregation across regions and price segments)				
	13/15		12/14	
Competitive Fringe model (HP, Compaq, Dell, IBM)				
US	4/4	4/4	3/3	3/3
EU	3/4	4/4	3/3	3/3
JP	3/4	4/4	3/3	3/3
Competitive Fringe model + MM contact (aggregation across regions)				
	3/4	2/4	3/3	2/3
Competitive Fringe model + MM contact (aggregation across regions and price segments)				
	1/4		2/3	
Tacit Coordination model (HP, Compaq, Dell, IBM)				
US	4/4	4/4	3/3	3/3
EU	3/4	4/4	3/3	3/3
JP	3/4	1/4	3/3	3/3
Tacit Coordination model + MM contact (aggregation across regions)				
	3/4	2/4	3/3	2/3
Tacit Coordination model + MM contact (aggregation across regions and price segments)				
	2/4		2/3	

Note: The Table reports the number of rejections at the 1% significance level of the null hypothesis of equality between the model-implied and CAPM betas against the two-sided alternative. For a given combination of rows and columns, the first number is the number of rejections, whereas the second number is the number of firms which operate in the market and for which the CAPM was estimated. Whenever the null was not rejected, the name of the firm is reported.

6.8 Testing the Difference between Critical and Estimated Discount Factors

Next, we consider how far apart critical discount factors are from the discount factors estimated using the finance models. We consider this issue by comparing the implied betas instead of discount factors directly since we estimated betas using a linear model so that approximate statistical tests are easier to deal with. To make the comparison we back out the betas implied by the critical discount factors and examine whether they are within the 99% confidence interval of the corresponding asset pricing betas.[58] For the great majority of the firms for which we estimate

[58] Obviously this is an approximate technique since a full statistical analysis would need to consider the way in which uncertainty in the demand estimates translated into our calculations of critical discount factors as well as accounting for the uncertainty arising from the stock market data underlying the finance models. While we could make assumptions such as

the cost of capital, it is very well approximated by the cost of equity since firms finance themselves using mostly equity (the only firms financed less than 90% by equity are SGI and Unisys).

Table 15 reports that, in the main, critical discount factors from our various models are significantly smaller than the estimated discount factors reflecting the firms cost of capital. In the benchmark model, no more than three have an implied beta which falls within the 99% confidence interval for the CAPM beta. By and large, this result is unaffected by multi-market contact and suggests that coordination would be sustainable if the benchmark model is a reasonable approximation to reality. Although critical discount factors rise once we allow for a competitive fringe, indicating that coordination appears harder to sustain in that model, we continue to find that in most instances the critical discount factors lie significantly below the estimated discount factors.

Conclusion

This paper attempts to take the coordination literature following Friedman (1971) seriously and to use it to understand the incentives to tacitly coordinate in a particular differentiated product market, the network server market. In doing so, we build on the literature on UEMS, the analysis of firm conduct, the theory of repeated games and the literature on asymmetry and coordination.

We find that in the benchmark tacitly collusive model (Friedman, 1971) the incentives to collude are substantial, even without assuming sophisticated punishment mechanisms. We find that the merger between HP and Compaq affects the incentive to cooperate, but that the merger actively *decreases* firms' incentives to tacitly cooperate. We show that such results will occur in a fairly wide range of circumstances, suggesting that ceteris paribus mergers will generally reduce the incentive to cooperate in the benchmark model. Intuitively, the result emerges because the unilateral effects of a merger will mean that Nash equilibrium payoffs will increase following the merger. In so doing, the return to cooperation falls.

We considered a number of generalizations. First, we considered multi-market contact, following Bernheim and Whinston (1990). Empirically, we found that multi-market contact generally amplifies the incentives to cooperate compared to the benchmark model. However, we found that critical discount factors may increase or decrease relative to their single market cases as multi-market contact pools IC constraints and in so doing means critical discount rates are effectively 'averaged'.

independence of the demand side and stock market beta estimates and then bootstrap test statistics, even that approach would remain approximate since to fully implement a statistical test we would need to know at least the correlation structure of all our estimated parameters. Since doing so would add a great deal of complication and not a great deal of additional insight we have not taken that route, despite the probable technical desirability of doing so.

Second, we considered the effect of a competitive fringe. Intuitively, we found that models incorporating a competitive fringe constrained the coordinating firms' ability to raise prices compared to a fully tacitly coordinating industry. However, we found that individual players can be either better or worse off when only a subset of firms tacitly coordinate. A smaller number of firms following the objective of maximizing total profits of the cooperating group may be able to improve the rewards paid to individual members of the smaller group since the objective of the group and its members are more closely aligned. On the other hand, individual players may be disproportionately affected by the competitive constraint from the fringe and so a partial coalition may choose to sacrifice individual firms' profitability for the overall benefit of the group. Clearly, such results will rely heavily on the detailed structure of payoffs in the industry.

Third, we introduced an antitrust authority into the model. We found that even a fairly small probability of a member of a tacitly coordinating coalition being fined by the antitrust authorities, as can happen at least in theory in a number of jurisdictions, would affect firms' incentives to cooperate in the server market. We found that for realistic fine levels (10% of revenue) and fairly small probabilities of being successfully prosecuted and fined by the antitrust authorities tacit coordination frequently ceases to be incentive-compatible. Such results may suggest that, even if the probability of a cartel being detected is small, the fines can be sufficient to affect the incentive to engage in coordinated behavior. Naturally, if the reader believes our estimate of being fined by a competition agency should, in truth be far smaller than the 1% chance we worked with, then the deterrence effectiveness of fines would become considerably smaller.

By way of closing remarks we first note that in modeling tacit coordination by following Friedman (1971) we make a number of very strong assumptions. In particular, our model is silent about entry and exit by either firms or products. In addition, we do not account for uncertainty and imperfect monitoring as in Green and Porter (1984). As is appropriate for a first piece of empirical work in an area, we recognize that these are strong assumptions and expect that future work simulating the coordinated effects of mergers will attempt to address each of these areas.

Finally, we should be absolutely clear what we are not arguing in this paper. Specifically, our point is not that mergers cannot, or even do not generally, have coordinated effects. Rather our message is more hopeful for coordinated theories of harm and yet also probably more challenging. Mergers we find can have coordinated effects but the precise mechanisms at work are currently not well understood and the tools for evaluating whether individual merger cases have coordinated effects are very limited. Building empirical models seems likely to help us understand the various mechanisms that can be at play and our aim has been to make a first albeit perhaps modest contribution in that process.

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Appendix: Proof to Proposition 1.

For non-merging firms $f \in \Im^{non-merging}$ **:** Since the vector of the industry profit maximizing tacitly collusive prices p^{Coll} are independent of market structure, $V_f^{Coll} \equiv \frac{\pi_f(p^{Coll})}{1-\delta_f}$ we have immediately that $V_f^{collusion}(\Delta^{pre}) = V_f^{collusion}(\Delta^{post})$ provided of course that the discount factors δ_f for those firms remain unchanged post-merger. Turning to the defection payoff, for any non-merging firm $\pi_f^{Def}(\Delta^{pre}) = \pi_f^{Def}(\Delta^{post})$ since collusive prices of rivals have not changed and neither has the profit function of the non-merging firm. Turning to the Nash payoffs, if a merger occurs between firms producing substitutes then absent efficiencies, all non-merging firms are (weakly) better off so that $\pi_f^{NE}(\Delta^{post}) \geq \pi_f^{NE}(\Delta^{pre})$ for all non-merging firms. Since $V_f^{Def} \equiv \pi_f^{Def} + \frac{\delta_f \pi_f^{NE}}{1-\delta_f}$, we can therefore write $V_f^{Defection}(\Delta^{pre}) \leq V_f^{Defection}(\Delta^{post})$ for all non-merging firms. Since $V_f^{collusion}(\Delta^{pre}) = V_f^{collusion}(\Delta^{post})$ and $V_f^{Defection}(\Delta^{pre}) \leq V_f^{Defection}(\Delta^{post})$ we have that if $V_f^{collusion}(\Delta^{pre}) < V_f^{Defection}(\Delta^{pre})$ so a non-merging firm was not willing to collude pre-merger then $V_f^{collusion}(\Delta^{post}) < V_f^{Defection}(\Delta^{pre}) \leq V_f^{Defection}(\Delta^{post})$ so that it is not willing to collude post-merger. Stated alternatively, we can write $V_f^{collusion}(\Delta^{pre}) - V_f^{Defection}(\Delta^{pre}) \geq V_f^{collusion}(\Delta^{post}) - V_f^{Defection}(\Delta^{post})$ for all $f \in \Im^{non-merging}$.

Merging firms $f \in \Im^{merging}$**:** Next notice that for any $f \in \Im^{merging}$ then since $V_f^{Coll} \equiv \frac{\pi_f(p^{Coll})}{1-\delta_f}$ while collusive prices are independent of who owns the products so that the profits attributed to any subset of products remains constant under collusion we can write (using admittedly slightly loose notation)

$\sum_{f \in \Im^{merging}} V_f^{collusion}(\Delta^{pre}) \geq \sum_{f \in \Im^{merging}} V_f^{collusion}(\Delta^{post})$ provided $\delta_f^{pre} \geq \delta_f^{post}$ for all $f \in \Im^{merging}$. Finally notice that aggregate static defection payoffs $\sum_{f \in \Im^{merging}} \pi_f(p_{\Delta^{post}}^{Def}) \geq \sum_{f \in \Im^{merging}} \pi_f(p_{\Delta^{pre}}^{Def})$ are always greater post-merger than pre-merger since the enlarged firm has greater flexibility to cheat by undercutting so cannot be made worse off in so doing than the sum of its constituent parts solving their analogous problems. Similarly, aggregate post-merger Nash equilibrium profits will be higher for the merged firm since any merger will (weakly) increase Nash equilibrium prices towards collusive

levels. Finally we note that $\sum_{f \in \Im^{merging}} \pi_f^{NE}(\Delta^{post}) \geq \sum_{f \in \Im^{merging}} \pi_f^{NE}(\Delta^{pre})$ since mergers in pricing games between firms producing products are profitable so that if, $\delta_f^{pre} = \delta_f^{post} = \delta$ for all $f \in \Im^{merging}$ then $\frac{\delta}{1-\delta}\left(\sum_{f \in \Im^{merging}} \pi_f^{NE}(\Delta^{post})\right) \geq \frac{\delta}{1-\delta}\left(\sum_{f \in \Im^{merging}} \pi_f^{NE}(\Delta^{pre})\right)$, and so $\sum_{f \in \Im^{merging}} \pi_f^{Def}(\Delta^{post}) + \frac{\delta}{1-\delta}\left(\sum_{f \in \Im^{merging}} \pi_f^{NE}(\Delta^{post})\right) \geq \sum_{f \in \Im^{merging}} \pi_f^{Def}(\Delta^{pre}) + \frac{\delta}{1-\delta}\left(\sum_{f \in \Im^{merging}} \pi_f^{NE}(\Delta^{pre})\right)$ which allows us to write $\sum_{f \in \Im^{merging}} V_f^{Defection}(\Delta^{post}) \geq \sum_{f \in \Im^{merging}} V_f^{Defection}(\Delta^{pre})$. This in turn implies that $\sum_{f \in \Im^{merging}} V_f^{collusion}(\Delta^{pre}) - \sum_{f \in \Im^{merging}} V_f^{Defection}(\Delta^{pre}) \geq \sum_{f \in \Im^{merging}} V_f^{collusion}(\Delta^{post}) \sum_{f \in \Im^{merging}} V_f^{Defection}(\Delta^{post})$ provided of course that $\delta_f^{pre} = \delta_f^{post} = \delta$ for all $f \in \Im^{merging}$. **Q.E.D**.