# A Full Equilibrium Relevant Market Test: Application to Computer Servers[1]

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August 8, 2005

[1] **Acknowledgements:** We are grateful to Philippe Gagnepain, Pedro Marín, Patrick Rey, Pierluigi Sabbatini, George Siotis, Lars Sørgard, Frode Steen and Frank Verboven for their comments and insights. For helpful discussions, we thank seminar participants at KU Leuven, the Norwegian Competition Authority and Universidad Carlos III. Any remaining errors in the paper are solely ours.

**Abstract**

The paper defines, implements and compares two empirical tests of relevant markets. While the European SSNIP test compares an initial industry equilibrium to an out-of-equilibrium situation, the FERM test compares the same initial equilibrium to an other equilibrium outcome. Hence, it is more in line with the behavioral assumptions of the underlying model of industry equilibrium and this can have significant consequences. We define these concepts formally and apply them to the industry of computer servers by estimating a model on a large dataset. We find several smaller relevant markets in the low-end segment of servers.



*Keywords*: relevant market tests, differentiated products, computer servers

*JEL classification*: C33, L41, L63

# 1 Introduction

A traditional step in antitrust investigation is to delineate the relevant market, which consists of all products competing with each other. This paper defines, implements and compares two empirical tests of relevant markets when products are differentiated. One is the SSNIP test. It is based on demand substitution and defines a relevant market as a set of products, whose prices can be raised jointly profitably. The other test is the Full Equilibrium Relevant Market (FERM) test. Based on both demand and supply substitution, it defines the relevant market as the set of products whose average price would be significantly raised at equilibrium if they were priced by a hypothetical monopoly or jointly determined by a cartel. The SSNIP test compares an observed industry equilibrium to a hypothetical out-of-equilibrium outcome. The FERM test, on the other hand, compares the same observed industry equilibrium to an other, hypothetical, equilibrium. This motivates its name as a 'full' equilibrium test. Hence, the FERM test is an attempt to exploit the structure of the underlying industry model. We define these concepts formally and apply them to the industry of computer servers that provides an excellent field of application.

Servers are at the core of hot policy debates. More precisely, the definition of relevant markets for server operating systems is a controversial issue in a recent antitrust case. We cannot address it due to data limitations that prevent us to separate the software from the hardware. Our focus is here on the market for servers which constitute a good candidate for illustrating our procedure because servers are highly differentiated. Indeed servers are key elements of computer networks enabling very different types of clients to access and use these networks. In other words, this paper is aimed at testing how our methodological concept can be applied in industry analysis.

To do so, we use a large, aggregate dataset of computer servers sold worldwide. We build and estimate an oligopoly model of differentiated products with discrete choice demand. Using this workhorse, we implement our relevant market tests. We find several smaller relevant markets, especially in the low-end segment. This suggests that differentiation is so strong that it constrains significantly substitution opportunities.

Its equilibrium nature makes the FERM test more consistent with the underlying economic theory. First, the FERM test takes into account that a hypothetical cartel would face different strategic responses from competitors. Second, the test evaluates proper multiproduct pricing strategy. None of these is true for the SSNIP test. Hence, as opposed to this latter, the FERM test might be able to provide a finer picture of the industry in question. The difference can be both quantitatively and qualitatively significant. We find examples in our application where the joint and uniform price rise in the SSNIP test is unprofitable, but the FERM test shows that, in the same case, due to proper multiproduct pricing strategy, a hypothetical cartel could profitably raise average price of its products. These differences would yield different conclusions about relevant market sizes and, hence, would support different policy decisions.

Given an estimated industry equilibrium model, the FERM test does not imply significantly larger computational complexity than the SSNIP test: The FERM test is technically not different from the methodology used to evaluate mergers in the literature on differentiated products markets, see e.g., Ivaldi and Verboven (2004). More precisely, it is equivalent to the measurement of effects of coordination due to a cartel. This is in line with the new European merger regulation. (See the Act of the European Council, 2004.)

Two contributions in relation with our paper are worth to be mentioned. Brenkers and Verboven (2004) estimate a discrete choice demand model for the European car industry and run SSNIP tests to find relevant markets. Their results suggest that rigorous econometric market testing procedures can delineate finer market structure than conventional wisdom. Van Reenen (2003) uses basically the same world-wide server data as we do and attacks the question whether low-end servers, in his definition, products below $100.000, are on the same relevant market as more expensive systems. From several demand models, he estimates price elasticity of this low-end group. Instead of implementing the SSNIP test, he argues that this elasticity is too low, meaning that there is no substantial substitution away from these products. Hence, he states that the relevant market can not be larger than the investigated group. It is interesting to note that our results do not validate the arbitrary threshold of $100.000 set by Van Reenen. We find more fragmentation.

Indeed, competition authorities most often do not implement relevant market tests rigorously. Our conclusion on this point is that proper application of SSNIP or FERM tests might result in more fragmented market structure. This, in turn, could change possible reactions of competition policy. For example, having many smaller relevant markets can be an argument against a proposed merger. That is why we emphasize the importance of implementation of more rigorous and formal testing procedures in such cases in order to support economic policy decision making.

The paper is organized as follows. Section 2 introduces formally the relevant market concepts. Section 3 discusses briefly the main features of the server industry. Section 4 builds up the model, whose estimation results are presented in Section 5. Section 6 discusses results from implementing the relevant market tests. Section 7 concludes.

## 2 Relevant market tests

The relevant market of a given product is the smallest set of products, including the product itself, which, as a whole, does not face significant competition from other products. That is, the only competitors of this given product are those in the set. A relevant market test is an algorithm that determines, which products belong to the relevant market of a given product. The size of the relevant market is crucial for competition policy, for example. A product, despite its low sales figures, can have large market share and, hence, potentially a large market power if its relevant market is small, everything being equal.

Any relevant market test is aimed at measuring the strength of competition a given product faces from other products. For example, in its guidelines to assess relevant markets, the EU Commission (1997) identifies three forms of competitive constraints: demand substitution, supply substitution and potential competition. Demand substitution is the most immediate competitive constraint on suppliers. At each decision, a producer must bear in mind that customers can change supplier relatively easily and quickly. Supply substitution refers to the strategic response of competitors to moves of the producer. The response of competitors can be fast when it is about to change their price, for instance. However, supply responses of competitors, when they involve significant additional investment (marketing efforts, product development for instance), can be much slower than demand substitution. Finally, potential competition means the entry of new competitors into the industry. This is the slowest competitive constraint.

The definition of relevant market must involve the degree to which each of these three competitive constraints are considered. From a competition policy perspective, it is worth to take into account only the fastest operating disciplinary forces at the market definition stage. The slower effects of competition are considered usually in a later phase of competition policy analysis (see e.g., again, the EU Commission, 1997).

The present paper defines and implements two relevant market tests, which differ in the degree to which they consider the various sources of competitive constraints in their underlying relevant market definitions. The SSNIP test considers only demand substitution, while the *Full Equilibrium Relevant Market* test, or FERM test, takes also into account strategic price adjustments of competitors, a form of quick supply substitution.

There is an other crucial difference between the two testing procedures. The SSNIP test compares the observed industry equilibrium to a hypothetical out-of-equilibrium situation. On the contrary, the FERM test compares the same observed equilibrium to an other, hypothetical, equilibrium, motivating the term 'full' in the name of the test. In other words, the FERM test takes into account more completely the structure of the underlying economic model. In this sense, its simulations are more realistic. Also, this equilibrium nature brings the FERM test closer to other methodologies used to support policy decision making, e.g., in merger evaluations. We will explore this point below too.

This section introduces these ideas formally in relation to a general differentiated products industry with oligopoly supply. In this industry there are $J$ differentiated products and $F$

multiproduct firms.[1] Each firm produces a mutually exclusive subset of the products. Let $q(p)$ be a $J$-dimensional vector function, which gives demand for each product as a function of the $J$x1 vector of prices $p$. On the supply side, there is a Bertrand pricing game[2]: Each producer chooses its own products' prices to maximize joint profits generated by this subset of products, taking into account that all the other competitors behave similarly. The Nash equilibrium of this game is given by the pricing function $p(q)$, which is a $J$-dimensional vector function that gives optimal prices as a function of any demand vector function. We define industry equilibrium as a Nash equilibrium of the pricing game and the corresponding vector of demands, where that latter is generated by the $q(.)$ function. Formally:

**Definition 1** *: Industry equilibrium. A nonnegative pair of* $J \times 1$ *vectors* $(\overline{p}, \overline{q})$ *constitutes an industry equilibrium if and only if* $\overline{p} = p(q(\overline{p}))$ *and* $\overline{q} = q(\overline{p})$.

Product level profits are given by $\pi(p) = (p - c) \bullet q(p)$, where $c$ is the vector of constant, product specific marginal costs. Also, denote the vector of consumer surpluses by $cs(p)$. Later in the paper, for all these functions we will provide parametric examples, which we estimate using real data. The next two subsections define the two alternative relevant market tests. The third subsection discusses some practical problems.

## 2.1 The SSNIP test

The SSNIP test bases its relevant market definition on demand substitution solely. The relevant market of a specific product $j$ is the smallest subset of products, including product $j$, for which applying a *Small but Significant, Non-transitory Increase in Price*, or SSNIP, to each element of this subset - letting prices of other non-included products unchanged - generates an increase in the level of joint profits. Formally:

**Definition 2** *: SSNIP relevant market of product* $j$*. Let* $M \subseteq J$ *and* $j \in M$*. Let* $(\overline{p}, \overline{q})$ *denote an initial industry equilibrium and* $\pi_i(p)$ *the profit generated by product* $j$ *when prices are given by* $p$*. Let* $p^{ssnip}$ *be a price vector whose* $j^{th}$ *element is equal to* $(1+\kappa)\overline{p}_j$ *if* $j \in M$*, and equal to* $\overline{p}_j$ *otherwise, where* $0 < \kappa \leq 0.1$*. Then,* $M$ *is the SSNIP relevant market of product* $j$ *if and only if*

*(i)* $\triangle\pi_M^{ssnip} \equiv \left( \frac{\sum_{j \in M} \left[\pi_j(p^{ssnip}) - \pi_j(\overline{p})\right]}{\sum_{i \in M} \pi_i(\overline{p})} \right) * 100 > 0$*, and*

*(ii) for all* $M' \subseteq J$*, such that* $j \in M'$ *and* $M'$ *satisfies (i):* $\#(M) \leq \#(M')$*.*

[1] $J$ also denotes the *set* of all products.

[2] The Bertrand assumption is not necessary. Our tests can be carried out using any other pricing and, hence, equilibrium assumption.

Condition (i) is the profitability criterion of the SSNIP, while condition (ii) states that the relevant market should be the smallest among those satisfying condition (i). The magnitude of the price increase is set by $\kappa$ and it usually takes a small value. The implementation of the SSNIP test is the following. Pick a product as a first candidate relevant market set, and check whether it satisfies the relevant market definition alone. If so, we conclude that this product constitutes itself the relevant market. If not, add an other product to the candidate relevant market set and do so until the test is satisfied. The set of products defined by this procedure constitutes the relevant market because the joint profits generated by these products increase when their prices increase.

The intuition is as follows. On the one hand, the price increase applied to the products included in the candidate relevant market raises markups. On the other hand, it diverts sales to products with unchanged prices. When the first effect dominates the second one, i.e. if joint profits increase, products outside the set do not provide a sufficiently strong competitive constraint in the form of demand substitution. In other words, the joint market power of the candidate relevant market is large enough to make the hypothetical price increase jointly profitable. If joint profits decrease, we conclude that the relevant market is larger than the candidate set.

In practice, when checking a given candidate set we proceed as follows. First, we estimate a parametric model of demand and pricing functions. This amounts assuming the observed data were generated by an industry equilibrium. Using estimation results, we calculate operating profits generated by each of the products belonging to the candidate set. By summation, we obtain the joint profit generated by the set. Second, we apply a price increase in a magnitude comprised between one and ten percent to all products belonging to the set, keeping unchanged the prices of other products. Using the estimated model we simulate how demand and, hence, profits are changed. Note that the outcome after the hypothetical price increase is not necessarily an equilibrium: Since the test considers only demand substitution we do not assume that competitors adjust their prices.

The SSNIP test is often called the 'hypothetical monopolist' test. Indeed, the test implicitly assumes that there is a hypothetical firm or decision maker, which coordinates the pricing of products in the candidate set and carries out the price increases. It is important to emphasize, however, that the hypothetical decision maker in the SSNIP test is a monopolist only in the sense that it controls a subset of all products, i.e., only on the candidate relevant market, while, in the economic literature, the term 'monopolist' usually refers to a firm monitoring all products in an industry. To avoid confusion, we do not use the term 'hypothetical monopolist' in the sequel and instead, we keep using the acronym SSNIP.

## 2.2 The FERM test

As already mentioned, the SSNIP test compares the estimated industry equilibrium to a hypothetical out-of-equilibrium outcome. It does not consider the strategic behavior of competitors as it only analyzes the effects of demand substitution. Now, if the prices of products in the candidate relevant market increase, producers of other products may respond strategically, e.g., by changing their prices. This price reaction could affect the delineation of the relevant market because it could modify the relative profitability of changes in prices. Consequently, the definition of the relevant market should account for the combined effects of short term demand and supply substitutability. To do so, we must relax the implicit assumption of absence of strategic behavior of agents, which they might never display in equilibrium. In other words, we should compare the initial industry equilibrium to an other equilibrium situation.

The objective is still to assess the joint market power embedded in the candidate relevant market $M$. To solve this exercise when competitors react strategically, we proceed as if a change in the product ownership structure of the industry occurs. Indeed, we consider that a hypothetical cartel is formed comprising all producers of the candidate set's products. It is equivalent to a hypothetical merger of these producers, which now behaves as a multiproduct firm. The cartel would maximize joint profits generated by its products, assuming price setters of other products react strategically. We propose to calculate the new equilibrium, associated with this ad hoc ownership structure, and compare before and after equilibrium prices and consumer surpluses. To do so, we define below criteria measuring the 'distance' between the initial and the partially collusive equilibria. A 'large' distance indicates that the market power embedded in the products of the candidate relevant market is significant and, hence, this candidate set can be thought of as a relevant market.

Let $(\overline{p}, \overline{q})$ be the initial industry equilibrium. Let $(p^{ferm}, q^{ferm})$ be the new industry prices and quantities, when the prices of products in the candidate relevant market set are set collusively by the hypothetical cartel. Define the following indices:

**Definition 3** *: Equilibrium Relevant Market Price (ERMP) and Equilibrium Relevant Market Consumer Surplus (ERMC) Indices for a set of products $M$:*

$$ERMP_M \equiv \left\{ \left( \frac{\sum_{j \in M} p_j^{ferm} \overline{q}_j}{\sum_{j \in M} \overline{p}_j \overline{q}_j} \right) - 1 \right\} * 100,$$

$$ERMC_M = \left\{ \left( \frac{\sum_{j \in M} cs_j^{ferm}}{\sum_{j \in M} \left[ cs_j^{ferm} + \left( p_j^{ferm} - c_j \right) q_j^{ferm} \right]} \right) / \left( \frac{\sum_{j \in M} cs_j}{\sum_{j \in M} \left[ cs_j + \left( \overline{p}_j - c_j \right) \overline{q}_j \right]} \right) - 1 \right\} * 100.$$

The first index, $ERMP_M$, is a measure of changes in prices of products in the candidate relevant market. The price of set $M$ is defined as the weighted average price of products in $M$. The index gives the percent change of this average price when the industry switches from its initial equilibrium to the partially collusive one. A large positive index indicates that the producers of products in the candidate relevant market can raise profitably their prices despite the competitors' strategic responses. This happens if the candidate relevant market is indeed a relevant market, that is to say, if its products' joint market power is sufficient large. As the weights in the formula for $ERMP_M$ are the quantities in the initial industry equilibrium, our measure is a Laspeyres index.

The index defined by $ERMC_M$ compares relative consumer surpluses. Here, relative consumer surplus is the ratio of consumer surplus generated by the products in $M$ to the total surplus generated by the same products. Total surplus is the sum of consumer surplus and producer profits. The $ERMC_M$ index is the percent change in this relative consumer surplus when equilibrium is switched. Relative consumer surplus describes the split of total welfare between consumers and producers. If, from one equilibrium to an other, consumer surplus decreases relative to total surplus, then the $ERMC_M$ index would be negative. Intuitively, the producers in the candidate relevant market join in a common multiproduct firm to obtain a larger share of total welfare. By lessening competition among their products, these producers jointly increase their market power. If all or most of the members in the candidate relevant market do not have outside competitors, that is to say, when the candidate set is a relevant market, then the cartel would bring a significant decrease in the intensity of competition that is translated into a 'significantly' negative value for the $ERMC_M$ index.

For both indices, the question is to *a priori* define when the distance between the two equilibria is considered as 'large'. A complete reply deserves further research. At this point, we assume that there exists a threshold value that defines a 'significant' change. It is an arbitrary step, analogous to the exogenously set price increase in the SSNIP test. In practice this threshold is supposed to take values in the range comprised between 5 and 15 percent. We give two FERM relevant market definitions, one for the $ERMP$ index and an other for the $ERMC$ index. Formally:

**Definition 4** *: FERM relevant market of product $j$ for index $ERMP$. Let $M \subseteq J$ and $j \in M$. Consider $\kappa$, a small positive value. Then, $M$ is the FERM relevant market of product $j$ if and only if*

*(i) $ERMP_M > \kappa$,*

*(ii) for all $M' \subseteq J$, such that $j \in M'$ and $M'$ satisfies (i): $\#(M) \leq \#(M')$.*

**Definition 5** *: FERM relevant market of product $j$ for index $ERMC$. Let $M \subseteq J$ and $j \in M$. Consider $\kappa$, a small positive value.. Then, $M$ is the FERM relevant market of product $j$ if and only if*

*(i) $ERMC_M < -\kappa$,*

*(ii) for all $M' \subseteq J$, such that $j \in M'$ and $M'$ satisfies (i): $\#(M) \leq \#(M')$.*

Conditions (i) state that the rise in equilibrium prices or the decrease in consumer surplus should be 'significant', and conditions (ii), again, state that the relevant market should be the smallest among those satisfying condition (i).

As we compare an initial equilibrium to an other equilibrium, the test is called a *Full Equilibrium Relevant Market* test. Note that it compares an observed or estimated equilibrium to a hypothetical and simulated equilibrium. Once an equilibrium model of an industry is obtained, i.e., has been estimated, the implementation of the FERM test is straightforward with a numerical routine.

Since it exploits the equilibrium structure of the underlying behavioral model, the FERM test should provide a finer picture of the investigated industry. For instance, as it properly takes into account the multipricing strategy of the hypothetical cartel, it allows the joint entity not to raise the prices of all its products at the same rate, because it considers the substitutions between these products, besides substitutions towards competitor products. This feature is confirmed in our application, where we provide evidences that the SSNIP test can be seriously misleading (see Subsection 6.2.). Summing up, the equilibrium nature of the FERM test and the fact that it is technically equivalent to the tools used to evaluate other policy questions, e.g., mergers, should make it more appealing from a policy perspective.[3]

## 2.3 Some practical problems: set expansion paths, multiplicity

The procedure to implement any of the relevant market tests starts by considering a given product as an initial set, and then add to this set other products until the 'smallest set' that passes the test is defined. At each step of this iterative process, the question is to choose the product to be added to the set. From a given product, many 'paths' can yield the same set. As long as the total number of products remains relatively small, examination of each path is feasible. As soon as the set of products becomes large, one must apply a short cut. Here, where the number of

[3] In the case of mergers, Michael Katz criticized the SSNIP test. In his lecture held at the UK Competion Commission in London (March 2004), he declares provocatively: " [...] *one could go so far as to question why one inquires at all about what a hypothetical monopolist would do. Rather than make predictions about a hypothetical monopolist, why not make predictions about actual suppliers? Specifically, why not ask directly whether the merging parties would find it profitable to raise price by a significant amount post merger? That is the question whose answer matters for cosnsumer welfare. If one possesses the answer to this question, the answer to the hypothetical monopolist question is completely superfluous."* Michael Katz goes further than we do in the sense that he proposes to omit relevant market testing completely in the case of merger evaluations. We retain from his declaration that supply side effects must be taken into account. We believe that improved tests for defining the relevant markets are useful as compagnon of more traditional approaches or methods.

potential paths is enormous, we propose to select the particular path that starts with the lowest priced product and to increase the set for the candidate relevant market by adding the second lowest priced product, and so on.

A related question is the possible multiplicity of relevant market sets. For a given product, one could find different 'smallest sets'. In small applications, one can test each possible combination and check for multiplicity of relevant markets. However, in large applications the number of combinations to be calculated and analyzed in a meaningful way is limited by computational feasibility. This might reduce the sharpness of conclusions to be drawn as, in such cases, there is an uncertainty on the precise definition of relevant markets. Comparing the results of different methods for defining relevant markets could be a way to reduce the risk of error in practice. For instance, to find many more relevant markets by applying our methodology than another procedure should invite to perform further investigation. Before going into the details of our model and results, however, we briefly describe the industry.

## 2.4 Relevant market definitions and competition policy

It is interesting to have a look at the relevant market definition process in the practice of competition policy. The SSNIP test we use in this paper is equivalent to the European Commission's definition (EU Commission (1997)):

> The question to be answered is whether the parties' customers would switch to readily available substitutes or to suppliers located elsewhere in response to a hypothetical small (in the range 5 % to 10 %) but permanent relative price increase in the products and areas being considered. If substitution were enough to make the price increase unprofitable because of the resulting loss of sales, additional substitutes and areas are included in the relevant market. This would be done until the set of products and geographical areas is such that small, permanent increases in relative prices would be profitable.

The US practice is different and has a longer history. First, the 1982 Merger Guidelines of the U.S. Department of Justice and the Federal Trade Commission gave the following definition:[4]

> [A] market is as a product or group of products and a geographic area such that (in the absence of new entry) a hypothetical, unregulated firm that made all the sales of those products in that area could increase its profits through a small but significant and nontransitory increase in price (above prevailing or likely future levels).

[4] The quotations below, as well as their sources, can be found, e.g., in Werden (2002).

In 1984, there was a small change in the text to make sure that the hypothetical firm is profit-maximizing. That is, the question is not whether a small price increase would be profitable but whether the profit maximizing hypothetical firm would indeed make the small price increase. That was not, however, a substantial change as the intention of the 1982 Guidelines was the same, the 1984 modification was only a clarification (see e.g. Werden (2002)). So, the 1984 MG definition is the following:

> Formally, a market is as a product or group of products and a geographic area in which it is sold such that a hypothetical, profit-maximizing firm, not subject to price regulation, that was the only present and future seller of those products in that area would impose a small but significant and nontransitory increase in price above prevailing or likely future levels.

The 1992 Merger Guidelines definition brings a slight but important change:

> A market is defined as a product or group of products and a geographic area in which it is produced or sold such that a hypothetical profit-maximizing firm, not subject to price regulation, that was the only present and future producer or seller of those products in that area likely would impose at least a small but significant and nontransitory increase in price, assuming the terms of sale of all other products are held constant. A relevant market is a group of products and a geographic area that is no bigger than necessary to satisfy this test.

This definition still assumes the profit maximizing behavior of the hypothetical firm of the candidate market but it constrains the price of competitor products to be unchanged. So, the definition of the European Commission is the SSNIP test of this paper, and the 1984 US Merger Guidelines definition is consistent with the FERM test. The 1992 MG definition is in between the two. It is similar to the FERM test since it looks for the profit maximizing price of the hypothetical entity of the candidate relevant market. However, as it assumes no price changes from the competitors, its outcome is out-of-equilibrium, and so, in this respect, it is like the European SSNIP test.

# 3 The computer server industry

Servers are important building blocks of computer networks. Most large organizations, such as private companies, government agencies, universities, build up their own computer networks, which interconnect different computer machines. The main task of these networks is to enable employees to communicate and access to various informations and services. A typical network consists of client and server computers. Client computers are most often PCs that, in particular, allow users to access servers of the network, besides storing data and running software applications. Servers connect clients and provide network services, which can vary from network to network. These services include: connecting clients to internal networks; authentication of users to define and apply access rights of different levels; storing data and files for common access to the network's clients; providing access to common printers; running e-mail services; faxing; providing access to large databases (e.g., financial, accounting), possibly with specialized software run on the server; running application softwares ('outsourcing') and providing extra computing power; running websites of clients; providing internet access; and providing security services (e.g., internet firewalls).

A server may not always provide all of these services. An organization may use several servers for different purposes, which may require to build more than one network. These networks, in turn, may or may not be interconnected. Moreover, both server and client computers have their own hardwares and softwares, which could be identical or could differ substantially. So one of the key issues in computer networking is the interoperability of client and server computers. Not surprisingly many server manufacturers emphasize that their servers interoperate seamlessly with any client server operating system. All these possible situations oblige the organization wishing to build its own network to choose a particular network architecture, or 'solution', which fits the best its goals. The same task can be accomplished, for example, using several smaller servers with one processor each or using one big, multiprocessor server computer. Optimality of these different architectures depends on network size, specificities of applications and the organization's existing networks.

Accordingly, server manufacturers differentiate their products substantially, not only by considering different technical characteristics, but also by applying different commercial approaches. There are three main business models. The first is the vertically integrated approach. In this business model, the manufacturer produce both hardware and software for servers. The main examples are IBM's mainframe computers, run under its proprietary operating system softwares, OS390 and OS400, or servers produced by SUN, SGI, HP or DEC, using their own proprietary flavor of the UNIX operating system. The advantage of the integrated approach is that producers can coordinate the joint development of hardware and software.

The second business model involves vertical disintegration. Here, manufacturers specialize either in software or hardware. The most common hardware configuration is based on Intel processors. The operating system software is proprietary, e.g., Microsoft's Windows or Novell's Netware. In the non-integrated approach, coordination between hardware and software firms is less tight than in the integrated case. However, significant standardization enabled manufacturers to gain from higher specialization, which is the main advantage of vertical disintegration.

The third business model is the open source approach. Here, as in the non-integrated approach, hardware is typically an Intel-compatible architecture. The software, however, is not proprietary. The most common open source operating system is Linux, which is considered by many as a UNIX clone, and whose source code is freely downloadable from the web. Furthermore, it can be freely modified and its developments are shared among members of the virtual programmer community via Internet.

Several server sellers use different business models in a parallel way. For example, IBM sells not only servers with its own proprietary operating system, but also machines with Linux installed on. Moreover, producers often sell not only servers, but also installation, training and maintenance services. In addition, companies often have their own IT departments and computer engineers or use outside consultants to build networks. All these make, the otherwise quite heterogenous, customers very well informed and, consequently, economic models of discrete choice demand and differentiated-products market particularly suitable for studying the server market.

We have a large data set, detailed in Appendix A, on servers sold worldwide. At this point we may make more precise the objective and the scope of our empirical analysis in relation with the policy debate which concerns servers. As it is known, the European Commission states that Microsoft uses its quasi monopoly on the PC operating system market to control interoperability on the market for low-end servers' operating systems to build up a dominant position in this market. (See Commission Decision, 2004). Part of the debate is about the size of relevant market for operating systems of workgroup servers, i.e., servers that perform file, print, group and user administration tasks. The Commission carried out its relevant market investigation based on customer surveys, from which it had micro level information on functionalities, interoperation properties, details on the type of operating systems, processors and multiple usages, as well as many qualitative information. From its study, the Commission claims that there is a relevant market for workgroup server operating systems[5]. Microsoft debated this claim.

The information available in our aggregate data set does not allow us to address this debate. For instance, we cannot identify multiple choices, nor different Windows operating systems. Nor do we observe server operating system prices and, hence, and perhaps even more importantly, we do not observe possible nonlinear pricing schedules between operating system sellers and hardware

[5]More precisely, the Commission proves that work group operating systems are not on the same relevant market as operating systems of large, enterprise level servers. The Commission does not investigate whether the group of work group operating systems can be split up into more, smaller relevant markets (i.e., condition (ii) of Definitions 2 and 4-5 is not investigated). This method of the Commission is practical since even this less precise characterization of relevant markets suffices for its goal.

manufacturers. To say something reliable about relevant markets of operating systems, these data, joint with additional modeling of the strategic game between these players, are essential. Because of the complexity of these issues, deriving price elasticities of operating systems from those of servers is here an insufficient approach to test relevant markets for operating systems.

Because of these constraints, we focus on the relevant market tests for server computers. The empirical application illustrates how our proposed methodology can be fruitfully applied in an industry analysis. To implement the implied relevant market tests, we first build an economic model of the industry.

# 4 The model

The market for servers is structured in three parts. First we describe demand for computer servers using a static discrete choice model. Second, on the supply side, a multiproduct oligopoly structure is constructed. Third, a Nash-Bertrand equilibrium assumption closes the model.

## 4.1 Demand

We use the standard methodology to model demand for differentiated products. This amounts to projecting products into the space of characteristics. Heterogenous customers value products through these projections. There are three regions: Japan, US and West Europe and twenty-one quarters of observations in each region. Each region-quarter pair is defined as a separate market. That is, customers located in a given region-quarter pair can make a purchase only at this market. In region $m$ at quarter $t$ there are $N_{mt}$ potential customers.

Customer $i$ on market $mt$ can choose among $J_{mt}$ differentiated products and the option of not buying anything (denoted by 0). Its conditional indirect utility from product $j$ is given by:

$$\begin{aligned} u_{ijmt} &= x_{jmt}\beta - \alpha p_{jmt} + \xi_{mt} + \xi_{jmt} + \varepsilon_{ijmt} \\ &\equiv \delta_{jmt} + \varepsilon_{ijmt}, \qquad j = 0, ..., J_{mt}, \end{aligned}$$

where $\delta_{jmt}$ is the mean utility, common to all customers at market $mt$, and $\varepsilon_{ijmt}$ is the customer-specific mean zero utility term. The mean utility depends on $x_{jmt}$, a $K$-dimensional vector of observed product characteristics; on $p_{jmt}$, the price of product $j$; on $\xi_{mt}$, a market-specific fixed effect; and on $\xi_{jmt}$, an unobserved product characteristic. We observe in $x_{jmt}$ such characteristics as number of processors or motherboard type. However, there are product characteristics known to the customer but not observed in the data, as, for example, quality of the hardware, quality of technical support or design. The effect of all unobserved product-specific variables, which affect utility by shifting product quality, is summarized by $\xi_{jmt}$. Customers can also choose an outside alternative by not buying any new server, which we denote as 'product' 0. This may reflect, for example, substituting computer servers by more traditional means of organizing the works of the customer or buying a used server or using an other information technology. The mean utility of the outside alternative is normalized to 0, i.e., $u_{i0mt} = \varepsilon_{i0mt}$.

Products also have characteristics that are varying across customers. Their contribution to utility is reflected by the term $\varepsilon_{ijmt}$. We have only market level data and no information on individual customer characteristics. Hence, the $\varepsilon_{ijmt}$ terms are unobserved too. We can, however, assume that they have a specific distribution. In general, it is natural to assume that the preferences of a given customer are not uncorrelated across products. For example, computer servers with the same operating system are certainly perceived by customers as closer substitutes than products with different operating systems.

For this reason, we adopt a nested logit model that collects products 'closer' to each other into separate groups. In particular, we partition all alternatives in a given market into $G$ mutually exclusive groups. These are, *G={SU, MP, 0}*, where $SU$ stands for workgroup servers with either uniprocessor or symmetric multiprocessing processor architecture, and $MP$ for servers with massively parallel processing architecture, and 0 for the outside alternative (this group has only one element). Each group, except group 0, has $H_g$ mutually exclusive subgroups, according to operating systems. That is, for *g=SU* and *MP*, *H*$_{\text{g}}$*={L, NW, NT, OS400, OS390, VMS, UNIX, O}*, where the subgroups are Linux, NetWare, Windows NT, IBM OS400 and OS390, Open VMS, Unix and other operating systems, respectively.

Based on this choice tree, we adopt three assumptions on the correlation structure of the $\varepsilon_{ijmt}$ terms. First, the $\varepsilon$'s are uncorrelated across customers and across region-quarter markets. Second, for a given customer, the $\varepsilon$'s belonging to the same group are more correlated with each other than with the $\varepsilon$'s of any other group. Third, for a given customer, the $\varepsilon$'s belonging to the same subgroup are more correlated with each other than with the $\varepsilon$'s of any other subgroup. Cardell (1997) shows that one can find such a distribution by writing

$$\varepsilon_{ij} = \varepsilon^i_{gmt} + (1-\sigma_G)\varepsilon^i_{hmt} + (1-\sigma_H)\varepsilon^i_{jmt}, \qquad j \in h \subset g, \quad \forall i, \forall j,$$

where $\varepsilon^i_{gmt}$, $\varepsilon^i_{gmt} + (1-\sigma_G)\varepsilon^i_{hmt}$, and $\varepsilon^i_{gmt} + (1-\sigma_G)\varepsilon^i_{hmt} + (1-\sigma_H)\varepsilon^i_{jmt}$ all have extreme value distribution, with $0 \leq \sigma_G \leq \sigma_H \leq 1$. is related to $\sigma_G$. The highest $\sigma_G$, the highest the correlation within the same group. Similarly, the highest $\sigma_H$, the highest the correlation among the same subgroup.

In other words, our nested logit model of customer choice has three hierarchical levels. At the top level, the customer decides among groups: whether to buy a computer server or not, and if so whether to buy a server with uniprocessing/symmetric-multiprocessing architecture or a machine with massively parallel multiprocessing architecture. At the middle level, he or she chooses among subgroups in the chosen group, i.e., among operating systems. At the bottom level, the customer chooses a server product from the chosen subgroup. The model is static, the three choices are made at the same time. The hierarchy reflects the assumption that customer preferences are more correlated for more 'similar' products, where this similarity is approximated by grouping[6].

Following McFadden (1981), if $0 \leq \sigma_G \leq \sigma_H \leq 1$ and $\alpha > 0$, then the preference structure is consistent with random utility maximization. That is, assuming that each customer chooses the alternative yielding the highest utility one can derive choice probabilities of each product. Furthermore, given our distributional assumptions, the market level choice probabilities, or market shares, at market $mt$ are:

$$s_{jmt} = \frac{\exp(\delta_{jmt}/(1-\sigma_H))}{D_{hg}} \frac{D_{hg}^{(1-\sigma_H)/(1-\sigma_G)}}{D_g} \frac{D_g^{1/(1-\sigma_G)}}{D}, \ j \in h \subset g, \ j = 0, ..., J_{mt},$$

where 'inclusive values' are defined as $D_{hg} = \sum_{j \in h \subset g} \exp(\delta_{jmt}/(1-\sigma_H))$, $D_g = \sum_{h \subset g} D_{hg}^{(1-\sigma_H)/(1-\sigma_G)}$, and $D = \sum_{g \subset G} D_g^{1-\sigma_G}$.

The formula of market shares can be log-linearized, as proposed by Berry (1994). Arranging and using vector notation, the result is:

$$\ln s - \ln s_0 = \delta + \sigma_H \ln s_{s/h} + \sigma_G \ln s_{h/g} + \xi,$$

where $s$, $s_0$, $s_{s/h}$ and $s_{h/g}$ are the $\left(\sum_{m,t} J_{mt}\right) \times 1$ vectors of market shares, the share of the outside alternative, within subgroup shares and shares of subgroups within groups, respectively. Unobserved product characteristics and mean utilities are stacked in the vectors $\xi$ and $\delta$, respectively. This latter can be further decomposed as $\delta = x\beta - \alpha p + \xi_m$, where $x$, $p$ and $\xi_m$ are the respective vectors of observed characteristics, prices and market specific fixed effects. Finally, the vector of demands is simply given by $q(p) = s(p)N$.

## 4.2 Pricing

We specify each market $mt$ as a multiproduct oligopoly. From now on, we suppress the subscript $mt$ without loss of generality. There are $F$ firms each producing a subset $J_f$ of the $J$ products. For firm $f$, profit equals the sum of its operating profits for each products minus its fixed cost $K$. The operating profit for product $j$ equals the sales of the product times the markup, which

[6] The nested logit model belongs to a subclass of the random coefficient model, popularized by Berry (1994) and Berry, Levinsohn and Pakes (1995). The BLP model is more general in specifying unobserved heterogeneity, we use nested logit only because of the ease of exposition. We should emphasize, however, that our tests can be used with BLP demand as well.

equals price minus the constant marginal cost $c_j$. Formally:

$$\Pi_f(p) = \sum_{j \in J_f} (p_j - c_j) q_j(p) - K$$

We assume Bertrand competition: Each producer sets the prices of its products so as to maximize its total profits, assuming that the others behave similarly. Each player has a similar trade off: On the one hand, increasing the price of one of its products increases the markup on this product. On the other hand, the same price increase decreases sales of the product by shifting customers towards other alternatives. In addition, a multiproduct firm takes also into account the fact that rising the price of a product shifts customers, partly towards its own other products, partly towards those of other producers. These arguments are summarized in the first-order condition associated with the profit maximizing price for product $j$ of firm $f$:

$$q_j(p) + \sum_{k \in J_f} (p_k - c_k) \frac{\partial q_k(p)}{\partial p_j} = 0.$$

The Nash equilibrium of the pricing game is a system of prices, which solves the corresponding first-order conditions of all products. To see this, we write the system of first-order conditions in vector notation. Define the $J \times J$ matrix $\theta$ as the firms' product ownership matrix, whose element $(j, k)$ equals 1 if products $j$ and $k$ are produced by the same firm, and 0 otherwise. Let $s(p)$ be the $J \times 1$ market share vector, $\nabla s(p)$ be the $J \times J$ Jacobian matrix of derivatives with respect to prices, and $c$ be the $J \times 1$ vector of marginal costs. With this notation, the $J$ first order conditions can be written as:

$$s(p) + [\theta \bullet \nabla s(p)'] (p - c) = 0,$$

where $\bullet$ denotes the element-by-element multiplication of two matrices of same dimension.

The $p$ vector of prices satisfying this matrix equation is the Nash equilibrium of the pricing game. Let us express this vector as:

$$p = c - [\theta \bullet \nabla s(p)']^{-1} s(p) \equiv c + m(s(p)),$$

that is, price equals marginal cost plus the markup. Finally, since we do not observe marginal cost directly we model it as a function of product characteristics:

$$c_j = w_j \gamma + \zeta + \zeta_j,$$

where $w_j$ is an $L$-dimensional vector of cost shifters, with the associated vector of parameters $\gamma$, $\zeta$ is a market specific fixed effect and the error term $\zeta_j$ summarizes the cost effect of unobserved characteristics for product $j$.[7]

[7] Note, again, that our data set is rather limited: we do not have cost observations. Additional information on this, joint with a more realistic model of costs, would certainly improve sharpness of conclusions from our relevant market testing procedures.

### 4.3 Correcting for computing power

Servers differ significantly both in price and in the scope and nature of tasks they can accomplish. A server machine can cost from a few thousand to several million dollars. Accordingly, they differ in capacity, computing power and the range of possible usages. Hence, if we are to measure substitutability of different machines, which is at the core of relevant market tests, we cannot compare directly, say, one unit of a large server system to one unit of a small workgroup server. Obviously, even if there is substitution between small and large machines there must be a scaling: Though tasks solved by a larger system cannot be solved by a much smaller machine, they can be accomplished, at least in principle, by using *several* smaller machines. In other terms, one should recognize the possibility of multiple choice. To fully address this question, one way is to use customer level data and to estimate a multiple discrete choice model as in Hendel (1999). As we only have aggregate data, we cannot identify the multiple choice structure in customer preferences directly. In our model, the customer can choose only one of the alternatives. However, we propose to account for this problem by modifying the measure of quantities in the model.

For each server model at a given region/quarter market, we multiply the quantity sold of the model by the number of CPUs. Implicitly, the customer now chooses between 'computing powers' or 'computer solutions', instead of just buying a certain number of server products. These 'solutions' are now the products and are highly differentiated. Their prices are determined by the prices of original server machines. Then, producers price the number of units of servers sold and customers value 'solutions'.

CPU numbers alone provide a rough measure of computing power. Ideally, one would control for computing power by taking also into account other characteristics like the speed of processor or the size of short run memory. Unfortunately, we do not have any of these variables. Hence, our choice is dictated by the lack of relevant quantitative variables in our dataset.

Accordingly, the demand and pricing equations are modified as:

$$\ln s^c - \ln s_0^c = \delta + \sigma_H \ln s_{s/h}^c + \sigma_G \ln s_{h/g}^c + \xi \tag{1}$$

$$p = c - \left[\theta \bullet (\nabla s^c(p) \bullet CP)'\right]^{-1} \left(D^{-1} s^c(p)\right) \equiv c + m(s^c), \tag{2}$$

where the superscript $c$ relates to the corresponding shares calculated from the quantity times CPU numbers variable, e.g. $s^c = s \bullet cpu$, where $cpu$ is the vector of CPU numbers; $D$ is a $J \times J$ diagonal matrix with $cpu_j$ in its $(j, j)$ position, for all $j$, zero elsewhere; $CP$ is a $J \times J$ matrix, whose $j$'th row's each element is $1/cpu_j$. Note that $\nabla s^c(p) \bullet CP = \nabla s(p)$ and $D^{-1} s^c(p) = s(p)$. The vector of predicted units sold as a function of prices remains $q(p) = s(p)N$.

Industry equilibrium is characterized by the pair of vectors $(p, q)$ satisfying equations (1)-(2). Assuming the observed data is generated by the equilibrium described above, the parameters to be estimated are $\alpha$, $\beta$, $\gamma$, $\sigma_H$ and $\sigma_G$.

# 5 Estimation

We use our large, aggregate data set, described in Appendix A, to estimate the model. Despite its size, the data set is not particularly rich in terms of explanatory variables (see Table 1 in Appendix C). We can capture computing power only in an approximative way and we do not observe customer level decisions. This lack of data has led us to drop a few observations corresponding to server systems priced above \$1 million, because it was fairly impossible to identify these products. After many experiments, dropping these data was the only solution to get reasonable estimates of marginal costs and markups for all other products. On the one hand, the difficulty we faced in integrating those few servers in our estimated model could be considered as an indication that these products are intimately so much different than the rest of the data that they can be excluded from the potentially largest relevant market. On the other hand, it is not clear what results one would obtain with appropriate micro level data, observing rich technical characteristics and customers' multiple choices, using a finer discrete choice model. Obviously, this feature reduces the sharpness of conclusions to be drawn. Nonetheless, despite the limitations of the data set, our estimation provides a relevant description of the working of markets for servers. The first subsection presents our econometric specification while the second one discusses the estimation results.

## 5.1 Econometric specification

From the loglinearized demand (1) and the first order conditions of price-equilibrium (2) we derive in Appendix B the two equations of the system to be estimated, that is to say:[8]

$$\begin{aligned} \ln s^c_{jmt} - \ln s^c_{0mt} &= x_{jmt}\beta - \alpha p_{jmt} + \sigma_H \ln s^c_{j/hgmt} + \sigma_G \ln s^c_{h/gmt} + \xi_{mt} + \xi_{jmt} \\ p_{jmt} &= w_{jmt}\gamma + m_{jmt}(s_{mt}) + \zeta_{mt} + \zeta_{jmt}, \qquad \forall j, \forall m, \forall t. \end{aligned}$$

The left hand side terms are the log market share minus the log of the market specific share of the outside good in the demand equation and the price in the price equation. The vectors

[8] We derive these forms analytically to reduce the computational burden. In principle, we could do the matrix inversion in (2) numerically during estimation. However, we can write the inverse analytically by using the economic structure of the model, see Appendix B. This increases the speed and accuracy of the estimation. Our method is similar to, although slightly different from, that of Foncel and Ivaldi (2004) and Verboven (1996).

of product characteristics, $x$ and $w$, comprises the same variables. These include dummies for operating systems, motherboard type and for rack optimized systems, variables indicating the number of CPUs, the CPU capacity and the number of rack slots. We interact all these variables with processor architecture dummies. In both equations, we estimate different coefficients on these characteristics for uniprocessor servers, symmetric multiprocessing servers and for massively parallel multiprocessing servers. Market specific fixed effects $\xi_{mt}$ and $\zeta_{mt}$, are specified as country and quarter dummies (interacted with architecture dummies).

The econometric error term of the demand equation is $\xi_{jmt}$, which we interpret as the unobserved quality of product $j$. Similarly, we define $\zeta_{jmt}$ as an unobserved cost shifter of the product. Hence, they are likely to be correlated with endogenous variables on the right hand side, namely, with prices and shares. This endogeneity problem necessitates instrumental variable estimation.

Following Berry (1994), we assume that the space of observed characteristics, spanned by $x$ and $w$, is exogenous. Berry, Levinsohn and Pakes (1995) describe that optimal instruments can be approximated efficiently by polynomial series. Furthermore, basis functions of these polynomials are also valid instruments and can be calculated easily for the model. So, we use the basis functions, as well as $x$ and $w$, as instruments. We estimate the system by nonlinear three-stage least-squares estimation. This exploits further correlation between the error terms of the two equations. Appendix A.3 provides the list of instruments.

## 5.2 Estimation results

Tables 2-4 present estimates. The coefficient on price ($-\alpha$) has the right sign and it is significantly different from zero. The values of density parameters describing unobserved heterogeneity of customers are consistent with random utility maximization (i.e., $0 \leq \sigma_G \leq \sigma_H \leq 1$). Both, $\sigma_G$ and $\sigma_H$ are significantly different from zero and 1. First stage R-squares for $\alpha$, $\sigma_G$ and $\sigma_H$ are 0.56, 0.84 and 0.46, respectively, and show that our instruments can capture movements of endogenous variables. When we regress estimated residuals from our demand and pricing equations on the instruments used F-tests show that these regressors are jointly insignificant in both case ($p$-values are 0.88 and 0.67 for the Nulls of joint insignificance). That is, our instruments are valid. A further evidence is that OLS estimate of $\alpha$ is 0.08, much lower than our 3SLS estimate. We know that uncorrected endogeneity problem in a demand system biases downward the price variable's coefficient in absolute value.

On the demand side, actual and potential number of processors (ccount and ccapac) are valued positively by customers. Note that, as it is corrected for 'computing power' (see subsection 4.3), the number of processors (ccount) is a relative measure. Rack optimized and PC servers provide higher value for customers. In general, the Open VMS is the least and the IBM OS390 is the most valued operating system. Time dummies are increasing over time, with some seasonality of the first quarter. On the supply side, we find, not surprisingly, that simpler CPU architecture servers (SMP and UP) have a cost advantage over more complicated MMP machines.

Implied mean marginal cost is 76% of price (with 23% standard deviation). Mean own price elasticity is 41%. The reason for this relatively high value is that it is an individual product level statistic: We have many products, especially at the low-end segment, which are close to each other in technical terms. A further evidence for this is that aggregate elasticity of products priced below \$100.000 is only 0.64%. The high number of relatively similar products can also explain the high values of preference parameters $\sigma_G$ and $\sigma_H$.

# 6 Implementing the SSNIP and FERM tests

As the number of products is large here, we cannot check all possible ways to construct the smallest set of products. We proceed as follows. We begin by taking all products priced below \$2000 as a candidate set and check whether it constitutes a relevant market[9]. If not, then we examine all products below \$3000. If this augmented set is still not a relevant market we continue expanding it by the next set of products between \$3000 and \$4000. We continue this procedure until finding a relevant market. Having done this, we repeat the procedure starting from the lowest priced products above the first relevant market.

This procedure can be implemented for a specific geographic market-quarter pair (e.g., Japan in the first quarter of 2001) or for some aggregate as well (e.g., all three geographic areas in the year 2000). We carried out simulations for the SSNIP tests by fixed-point iterations. A typical calculation for a country/quarter pair (around 400 observations) took about 15 seconds on a standard laptop PC. FERM simulations are computed using a Davidon-Fletcher-Powell-type quasi-Newton method. Here a typical simulation took about 45 seconds.

## 6.1 SSNIP results

Table 5 presents results for a 5% SSNIP test for the first quarter of 2001 in the US. That is, we calculated profit changes in this region/quarter pair from a hypothetical 5% increase in the price of the corresponding sets. The first two columns define a candidate relevant market: In each row, the first column gives the lower price limit of the candidate relevant market, while the second column gives its upper price limit. All products priced between these two limits belong to the candidate set. The last column gives $\triangle\pi_M^{ssnip}$, i.e., the percent change in total profits.

[9] There are no products priced below \$1000 in the data. That is why we start our procedures by a set bounded above by \$2000.

For example, the second row of the table shows that the first candidate relevant market examined is the set of products priced below $2000. A 5% increase in the price of these products decreases their profits by 0.4%. Hence, we augment our candidate relevant market set by adding products priced between $2000 and $3000. The result from a 5% SSNIP, displayed in the third row, is a 0.2% decrease in profits. So, we still did not find a relevant market and proceed by expanding the candidate set. This is done in the fourth row, where we find that products priced below $4000 constitute a SSNIP relevant market since their joint profits increase (by 1.4%) following a 5% price increase. Similarly, we find a second relevant market (products priced in the range $4000-$8000) and a third one too (range $8000-$400,000). In all these tables horizontal lines separate relevant markets.

Figure 1 summarizes the same information. Here, the horizontal axis represents the upper price limit of candidate sets, and the vertical measures percentage changes in profits. There are three series displayed: The first, PL_0, where all servers priced below in the upper limit are in the tested set. The second, PL_4000, where the lower bound of the tested set is $4000, and the third, PL_8000, where this lower limit is $8000. The boundaries of relevant markets are at the points where the series turn to the positive region, i.e., above the horizontal axis.

As for Europe and Japan, Table 6-Figure 2 and Table 7-Figure 3 displays the 5% SSNIP test results, respectively. In Europe, we find relevant markets with the same size as in the US. In Japan, the picture is slightly more fragmented. The basic pattern in all three cases is similar: one can identify several smaller markets below $25,000.

Tables 8-10 summarize results from 10% SSNIP test, i.e., in these cases we simulated the effects on profits from 10% price increases in the candidate sets. In general, the size of relevant markets increase and, in the case of US and Europe, the method cannot even identify the third relevant market anymore. The reason for this is that a 10% general price increase involves much bigger demand substitution than a 5% one. As a result, one must include more products in the candidate set to have increasing joint profits. Even in this stronger test, however, the general pattern remains, which shows several smaller relevant markets in the low-end part of the product scale. In some sense the SSNIP tests, when it is fully implemented, is able to account for the high differentiation of servers.

## 6.2 FERM results

Tables 11-16 display results from the FERM test simulations. The structure of tables is similar to that of the previous ones in that the first two columns define a candidate relevant market by giving the lower and upper price limits, respectively. In the tests displayed in Tables 11-13 decision is based on $ERMP_M$, which gives the percent change in the price of the candidate set when the industry switches from its initial equilibrium to the partially collusive one. The value of this index is represented in the last (the fourth) column. These tests define a relevant market when the index first goes above 10%. Tests in Tables 14-16 are based on the relative consumer surplus index, $ERMC_M$, which is represented in the fourth column. Here, a relevant market is defined when the value of the index is less then -15%. As previously, horizontal lines within tables indicate bounds of relevant markets found.

From Tables 11-13, we observe that, except for the US, the first relevant markets found by 10% FERM tests, i.e., products priced below $4000, are identical to those found in basically all SSNIP tests. Above these, the second and third relevant markets are pretty close to SSNIP results. However, FERM tests identify more relevant markets, that is, they display more segmentation, especially at the low-end regions. We also ran 5% tests and found even more segmentation. That can be because the FERM test takes also account strategic responses of rival producers. Here substitution comes not only from the demand but also from the supply side. More substitution makes easier for a given candidate set as to qualify as a relevant market. The size of higher-end relevant market is more ambiguous, which reflects perhaps the shortcoming we outlined above that it was not possible to set up a demand model including the largest, i.e., above $1 million, server systems. These latter omitted products are certainly true competitors of those products we could not classify in relevant markets above. Figures 4-6 summarize information of Tables 11-13 in a graphic way.

The relative consumer surplus based FERM tests, presented in Tables 14-16, show an even more fragmented picture. Using this decision rule, we find several smaller relevant markets in the low-end and middle region. In the case of Europe and Japan, we even find one in the higher end of our data used. The result that comes out clear from comparison of the previous tests is that low-end servers, defined roughly as products below $25,000, are not on the same relevant market as higher-end server systems. The same conclusion would have applied if we had started to build up candidate sets from the highest price towards lower levels.

Tables 17-19 provide comparative summary statistics by geographical areas. Both, the SSNIP and FERM tests find several relevant markets in the low-end segment. Especially the 5 and 10% SSNIP tests give similar results as 10% FERM tests using the ERMP criterion. However, the FERM test has a stronger tendency to deliver smaller relevant markets as the decision criterion becomes stronger. As we explained, this test takes into account possible strategic behavior of all market players. Hence, it is more realistic and is able to detect finer movements in the industry. As a consequence, with appropriate data, the FERM test can delineate more accurately possible relevant markets than the traditional SSNIP test.

Finally, let us illustrate the difference between the two approaches by a revealing example. The second line in Table 8 presents the result of a 10% SSNIP test for Q1 2001 US. The candidate relevant market is products priced below \$3000 and profits decrease by 0.6% after all product prices in the candidate set were increased by 10%. The second line of Table 11 presents the FERM test results for exactly the same case. Here, the hypothetical cartel increased *average* price almost exactly by 10%! But of course this increase is profitable. This is due to appropriate multi-product pricing. By not taking into account own product substitutions and strategic responses from competitors the SSNIP test can be misleading.

# 7 Conclusions

In general terms, we establish here that the econometric estimation and testing of relevant markets outlined above is fruitful as a supportive tool of economic policy decision making. More specifically, we define two empirical tests of relevant markets and outline their implementation strategies. As an example, we build and fit an equilibrium model on a large aggregate data set on the computer server industry. Using estimation results it is equally easy to implement the SSNIP and FERM tests.

In all considered cases, we found several smaller relevant markets and probably many more that we could expect. One reason for this result can be found in the high degree of differentiation among servers that constrains significantly substitution opportunities. The other reason is simply the fact that we apply rigorously the principles of relevant market definitions. In practice, relevant market definitions are not implemented formally, they are used only as a framework of thinking about the problem. The proper application of tests might result in more fragmentation in the market structure found. This conclusion can be important for example in merger cases.

Although both tests can detect market segmentation, the FERM test is able to provide an even finer picture of an industry. This follows from its greater consistency with the underlying economic theory, as opposed to the out-of-equilibrium nature of the SSNIP test. In our application, the consequences of this difference are quantitatively significant too. Hence, the FERM test should provide a more accurate tool for economic policy analysis.

As for the specific case of servers, we see two main areas whose more detailed information can be important and could even change both, qualitative and quantitative results. First, customer level information could tell us many things about patterns of *multiple purchases* and network architecture. From here, we could see more clearly substitution patterns, which are crucial in relevant market testing. Second, micro level data could also unveil *usage* of server products. This, again, would lead to a finer map of customer preferences. For example, internet 'outsourcing' can make such server products closer substitutes, which might not have been before. These patterns, of course, cannot be seen in our aggregate data set. Nevertheless, we should point out that the emphasis of this paper is on relevant market testing procedures, and these, with appropriate changes, can also be applied to models using micro level data.

# A Data

## A.1 Data collection and description

The data are available from IDC, a marketing firm. IDC collects server data in a quarterly/annual framework built up from three main tiers (IDC (1998)). These are vendor polling, financial modeling and end-user channel surveying. The final data base is set up from these three sources after numerous and rigorous cross-checkings. In the vendor polling phase, major vendors, channel and supplier partners are interviewed, using an electronic polling form. This takes place on a quarterly, regional, country and worldwide basis. The main informations collected are vendor, family and model data, initial server shipments (ISS) and upgrade shipments, operating system shares, pricing, CPU and configuration data.

In the next step, IDC uses detailed financial models to decompose factory revenues to the vendor, family and model level. Various publicly available financial information sources, press releases and third-party reports are used. Results are cross-checked with vendor polling data to have consistency. Finally, IDC interviews thousands of end-users on an annual basis. It surveys companies from all sizes, all industries and all geographical territories. Installed base, shipment and revenue data are cross-checked with previous results. Having finished all three steps, a further global preprogrammed cross-checking is run.

The final dataset includes quarterly observations of three countries/regions (Japan, USA, West Europe) for the period Q1 1996 - Q4 1997, and of eighteen countries (Austria, Belgium, Denmark, Finland, France, Germany, Greece, Ireland, Italy, Japan, The Netherlands, Norway, Portugal, Sweden, Spain, Switzerland, UK and USA) for the period Q1 1998 - Q1 2001. That is, in the first part of the sample we have only aggregate data for West Europe and country level observations in the second part. In all geographic territory/quarter pairs, we have observations for the major vendors (their total number is 36), their server families and models. For each vendor/family/model slot, we observe technical characteristics like operating system (Linux, Windows NT, NetWare, IBM OS400 and OS390, Unix, VMS and other); CPU type (IA32, CISC, RISC); CPU architecture (UP, SMP, MPP); CPU capacity; CPU count; a dummy for whether the system is rack optimized; the number of rack slots; and a dummy for PC servers. Also, we observe the number of shipments, either initial server shipments (ISS) or upgrades; and customer revenues.

IA32 type CPUs are the Intel architecture-based 32-bit processors, including Pentium, Pentium Pro and Deschutes processors. CISC, which abbreviates complex instruction set computers, is the traditional type of processing. These computers have large instruction sets, with both simple and complex instructions of variable lengths. RISC, reduced instruction set computers, have a processor design with smaller instructions set, with fixed-length formats. It is produced by Digital, IBM, Hewlett-Packard, Silicon Graphics and Sun Microsystems. These servers typically support Unix platform software.

There are three CPU architectures observed. UP denotes uniprocessor servers, which contain only one processor. SMP, symmetric multiprocessing, denotes the capability of the architecture to support more than one processors, symmetrically. This latter means that processors have equal access to storage devices. SMP is a generalization of the UP structure, hence SMP computers can use programs written for UP machines. MPP denotes massively parallel processing, where typically a large number of processors is used, but they are not treated symmetrically in the architecture.

The CPU count is the average number of CPUs shipped per model, at a given geographical area/quarter pair. CPU capacity is the maximum number of possible CPUs per server model. It is an integer, ranging from 1 to 128. PC servers are desktop systems designed specifically as servers. These have typically enhanced capacity and redundant hardware components, relative to 'ordinary' PCs, and have Intel architecture.

Customer revenue is the sum spent on a given model, at a given market. It includes the price of all shipments, peripherals attached by channel and channel margin. It is measured in current US dollars. We calculate the price paid by a customer for a given model by dividing customer revenue by the number of shipments.

## A.2 Necessary transformations

Since our theoretical model is microeconomic we need relative prices, instead of nominal ones. We choose to use real prices. These are calculated as follows. First, for a given model sold in a given country/quarter market, from the current dollar price we calculate current price denominated in the currency of the country. We use the quarterly average dollar market exchange rate[10]. Next, we calculate real price by dividing home currency denominated price by the country's consumer price index, which we normalize to 1 in Q1 1996. Finally, we multiply the resulting real price, at each quarter and country, by the constant, average Q1 1996 dollar/home currency exchange rate. This gives real prices denominated in a common currency: the 1996 first quarter dollar. This price is real in the sense that it measures the price of a given server system, sold in a given country, relative to the 1996 first quarter value of the CPI basket of this country. It is expressed in terms of average Q1 1996 dollar to get comparability not only within but also across countries.

In the first part of the sample, i.e., from Q1 1996 to Q4 1997, to calculate the necessary CPI index and exchange rate for Western Europe we use the fact that in the second part of

[10] All necessary macroeconomic series were downloaded from IMF's IFS database and from the OECD website.

the sample we have country level observations in this region. For the first sample period, we calculate a weighted average of CPIs of the sixteen European countries found in the second part of the sample. Weights are proportional to average total customer spending on servers in these countries between Q1 1998 and Q1 2001. The aggregate dollar exchange rate series is calculated similarly. Note that we could have used some official series, the euro exchange rate and the euro zone or EU15 CPI, for example. These series, however, cover a slightly different set of countries that we have in our data. Moreover, official weightings are more related to differences in general consumption structures across countries. Using server expenditure based weights is more appropriate in our application, as it tracks more closely the general price inflation hitting server product customers. That is, we take into account more efficiently the mass of information we have.

To calculate shares, we must determine the number of potential customers $N_{mt}$ at a given country/quarter pair. We follow Ivaldi and Verboven (2004) choosing first a market specific base quantity and make $N_{mt}$ proportional to it. The coefficient of proportionality is called by Ivaldi and Verboven the potential market factor. We choose the yearly average of employment level of a given country as a base quantity in a given country/quarter pair, or $E_{myt}$, where $yt$ denotes the year of quarter $t$. This assumes that computational needs of customer companies depend on the number of their employees. Most generally, computer servers are used to organize work. Although in some cases they are substitutes of human work, increasing employment surely increases the number and complexity of companies' tasks related to organization of work. This is the underlying rationale to use the aggregate employment level as the base quantity. Then, $N_{mt} = (1 + \tau)E_{myt}$, where $\tau$ is the potential market factor, whose value, after a number of trials, we set at -0.96. Product shares are given by shipments divided by the number of potential consumers. We use initial server shipments only and exclude upgrade shipments.

For the second part of the sample, i.e., from Q1 1998 to Q1 2001, we aggregate observations from Western European countries into one single region. Observations belonging to the same quarter, vendor, family, server model, operating system, CPU architecture, server class (PC server or not), rack type (rack optimized or not) are aggregated into one. Shipments and employment are summed, while CPU capacity, CPU count and rack slot numbers are averaged, weighted by shipments. For each individual European country, we calculate real prices as described above. These are averaged using shipments as weights, again. So, in the final data set we have observations in three regions for the whole sample period: Japan, US and Western Europe. We restrict our analysis to servers priced below $1 million. The list of variables is displayed in Table 1. The total number of observations used in estimation is 32273.

## A.3 Instruments

To estimate our model, we use the following instruments for a given product at a given region-quarter market. First, the exogenous characteristics of the product. Second, we use a set of polynomial basis functions of exogenous variables exploiting the three-way panel structure of our data: We calculate instruments from the same market: the number of other products of the same producer, the sum of CPU capacities of rival producers' products, the number of firms; also, the number of other products of the same producer and the number of firms in the same group; finally, the number of other products of the same producer in the same group and same subgroup. Instruments from the other two regional markets at the same time are: the number of other products of the same producer, the sum of CPU capacities of rivals' products; the number of competitors producing products in the same group and the number of competitors producing products in the same group and same subgroup. Finally, we use also the number of other products of the same producer at the same regional market, in different time periods; and the number of other products in the same group and same subgroup, of the same producer at the other two regional markets, in different time periods.

# B Product specific markups

We derive the markup $m_j$ charged by firm $f$ on a product $j$, which belongs to group $g$ and subgroup $h$ and it is sold on a specific region/quarter market $mt$, as a function of quantities and parameters only. First, define $q_j^c \equiv q_j * cpu_j$, where $q$ is the quantity sold and $cpu$ is the number of CPUs of the product. Define $Q^{cg}$ and $Q^{chg}$ as $\sum_{i \in g} q_i^c$ and $\sum_{i \in h \subset g} q_i^c$, respectively. Also, define $d_{hg} \equiv (\frac{1}{1-\sigma_H} - \frac{1}{1-\sigma_G})\frac{1}{Q^{chg}}$, $d_g \equiv \frac{\sigma_G}{1-\sigma_G}\frac{1}{Q^{cg}}$ and $d_0 \equiv \frac{1}{N_{mt}}$. Then, own and cross price-derivatives are

$$
\begin{aligned}
\frac{\partial q_j^c}{\partial p_j} &= \alpha q_j^c[-\frac{1}{1-\sigma_H} + q_j^c(d_{hg} + d_g + d_0)], \\
\frac{\partial q_j^c}{\partial p_i} &= \alpha q_j^c q_i^c (d_{hg} + d_g + d_0), i, j \in h \subset g, i \neq j, \\
\frac{\partial q_j^c}{\partial p_i} &= \alpha q_j^c q_i^c (d_g + d_0), i, j \in g, i \in h' \subset g, j \in h \subset g, h \neq h', \\
\frac{\partial q_j^c}{\partial p_i} &= \alpha q_j^c q_i^c d_0, i \in g' \subset g, j \in g \subset g, g \neq g'.
\end{aligned}
$$

Operating profit of firm $f$ is given by

$$\pi^f = \sum_{j \in S^f} (p_j - c_j) q_j(p),$$

where $S^f$ denotes the set of products sold by the firm at market $mt$. The first order condition of profit maximum with respect to the price of product $j$ is:

$$\begin{aligned} 0 &= \frac{\partial \pi^f}{\partial p_j} = q_j + (p_j - c_j)\frac{\partial q_j}{\partial p_j} + \sum_{i \neq j, i \in S^f} (p_i - c_i)\frac{\partial q_i}{\partial p_j} \\ &= q_j + (p_j - c_j)\frac{\partial q_j^c}{\partial p_j}\frac{1}{cpu_j} + \sum_{i \neq j, i \in S^f} (p_i - c_i)\frac{\partial q_i^c}{\partial p_j}\frac{1}{cpu_i}, \end{aligned}$$

where we used the fact that $\frac{\partial q_i}{\partial p_j} = \frac{\partial q_i^c}{\partial p_j}\frac{1}{cpu_i}$. Substituting own and cross price derivatives and using the definition of $q_j^c$ we can write:

$$\begin{aligned} 0 &= q_j + q_j cpu_j \frac{\alpha}{1-\sigma_H}(p_j - c_j)\frac{1}{cpu_j} \\ &\quad + \alpha q_j cpu_j d_{hg} \sum_{i \in h \cap S^f} (p_i - c_i) q_i cpu_i \frac{1}{cpu_i} \\ &\quad + \alpha q_j cpu_j d_g \sum_{h' \in g} \sum_{i \in h' \cap S^f} (p_i - c_i) q_i cpu_i \frac{1}{cpu_i} \\ &\quad + \alpha q_j cpu_j d_0 \sum_{g' \in G} \sum_{h' \in g'} \sum_{i \in h' \cap S^f} (p_i - c_i) q_i cpu_i \frac{1}{cpu_i}. \end{aligned}$$

Simplifying and rearranging gives the markup as a function of markups, quantities and parameters:

$$\begin{aligned} (p_j - c_j) &= (1-\sigma_H)[\frac{1}{\alpha} + cpu_j[d_{hg} \sum_{i \in h \cap S^f} (p_i - c_i) q_i \\ &\quad + d_g \sum_{h' \in g} \sum_{i \in h' \cap S^f} (p_i - c_i) q_i + d_0 \sum_{g' \in G} \sum_{h' \in g'} \sum_{i \in h' \cap S^f} (p_i - c_i) q_i]]. \end{aligned}$$

The goal is to express markup as a function of quantities and parameters only. Multiply both sides by $q_j$ and sum up over $j \in h \cap S^f$:

$$\begin{aligned} \sum_{j \in h \cap S^f} (p_j - c_j) q_j &= \frac{1-\sigma_H}{\alpha} Q^{fhg} + (1-\sigma_H) Q^{cfhg} [d_{hg} \sum_{i \in h \cap S^f} (p_i - c_i) q_i \\ &\quad + d_g \sum_{h' \in g} \sum_{i \in h' \cap S^f} (p_i - c_i) q_i + d_0 \sum_{g' \in G} \sum_{h' \in g'} \sum_{i \in h' \cap S^f} (p_i - c_i) q_i], \end{aligned}$$

where $Q^{fhg} \equiv \sum_{i \in h \cap S^f} q_i$ and $Q^{cfhg} \equiv \sum_{i \in h \cap S^f} q_i^c$. Introduce further notation: $\Gamma_{hg} \equiv \frac{1-\sigma_H}{\alpha} Q^{fhg}$ and $\Lambda_{hg} \equiv (1-\sigma_H) Q^{cfhg}$. Then, solving for the fixed point:

$$\begin{aligned} \sum_{j \in h \cap S^f} (p_j - c_j) q_j &= \frac{\Gamma_{hg}}{1 - d_{hg}\Lambda_{hg}} + \frac{\Lambda_{hg}}{1 - d_{hg}\Lambda_{hg}} [d_g \sum_{h' \in g} \sum_{i \in h' \cap S^f} (p_i - c_i) q_i \\ &\quad + d_0 \sum_{g' \in G} \sum_{h' \in g'} \sum_{i \in h' \cap S^f} (p_i - c_i) q_i]. \end{aligned}$$

Similarly, we sum up this expression over $h \in g$, introduce notation: $\Gamma_g \equiv \sum_{h\in g} \frac{\Gamma_{hg}}{1-d_{hg}\Lambda_{hg}}$, $\Lambda_g \equiv \sum_{h\in g} \frac{\Lambda_{hg}}{1-d_{hg}\Lambda_{hg}}$, and solve for the fixed point:

$$\sum_{h\in g}\sum_{j\in h\cap S^f}(p_j-c_j)q_j = \frac{\Gamma_g}{1-d_g\Lambda_g} + \frac{\Lambda_g}{1-d_g\Lambda_g}[d_0\sum_{g'\in G}\sum_{h'\in g'}\sum_{i\in h'\cap S^f}(p_i-c_i)q_i].$$

Finally, sum up over $g \in G$, let: $\Gamma_0 \equiv \sum_{g\in G}\frac{\Gamma_g}{1-d_g\Lambda_g}$, $\Lambda_0 \equiv \sum_{g\in G}\frac{\Lambda_g}{1-d_g\Lambda_g}$, and solve for the fixed point:

$$\sum_{g\in G}\sum_{h\in g}\sum_{j\in h\cap S^f}(p_j-c_j)q_j = \frac{\Gamma_0}{1-d_0\Lambda_0} \equiv \Sigma_0.$$

Then,

$$\begin{aligned}\sum_{h\in g}\sum_{j\in h\cap S^f}(p_j-c_j)q_j &= \frac{\Gamma_g}{1-d_g\Lambda_g} + \frac{\Lambda_g}{1-d_g\Lambda_g}d_0\Sigma_0 \equiv \Sigma_g,\\ \sum_{j\in h\cap S^f}(p_j-c_j)q_j &= \frac{\Gamma_{hg}}{1-d_{hg}\Lambda_{hg}} + \frac{\Lambda_{hg}}{1-d_{hg}\Lambda_{hg}}[d_g\Sigma_g + d_0\Sigma_0] \equiv \Sigma_{hg},\end{aligned}$$

which gives us

$$m_j = p_j - c_j = (1-\sigma_H)\left\{\frac{1}{\alpha} + cpu_j[d_{hg}\Sigma_{hg} + d_g\Sigma_g + d_0\Sigma_0]\right\}.$$

# C Tables

Table 1: List of variables

| variable | description | mean* | st dev* |
|---|---|---|---|
| IA32 | Intel architecture based processors | 64% | 48% |
| CISC | complex instruction set computers | 9% | 29% |
| RISC | reduced instruction set computers | 26% | 44% |
| UP | uniprocessor servers | 26% | 44% |
| SMP | symmetric multiprocessing servers | 72% | 45% |
| MPP | massively parallel processing servers | 2% | 13% |
| RACK | Rack optimization dummy | 3% | 17% |
| UR | Number of rack slots | 1.5 | 3.2 |
| SERVER | PC servers | 40% | 49% |
| LINUX | Linux operating system | 7% | 25% |
| NT | Windows operating system | 20% | 40% |
| NETWARE | Novell's operating system | 15% | 35% |
| OS400 | IBM's operating system | 3% | 17% |
| OS390 | IBM's operating system | 3% | 17% |
| UNIX | Unix operating system | 2% | 14% |
| VMS | Open VMS operating system | 32% | 47% |
| OTHEROS | other operating system | 18% | 39% |
| CCOUNT | number of CPUs | 2.7 | 14.4 |
| CCAPAC | maximum number of CPUs possible | 6.0 | 39.7 |
| PRICE | real price in millions of Q1 1996 USD | 0.1 | 0.2 |
| JA | Japan | 22% | 41% |
| US | USA | 40% | 49% |
| WE | Wester Europe | 39% | 49% |
| Total number of observations | 32273 | | |

*Means and standard deviations are percentages if the variable is a dummy and scalars otherwise.

## C.1 Parameter estimates

Table 2: Main Parameters of Interest

| parameter | estimate | st dev |
|---|---|---|
| $\alpha$ | 10.506 | 0.134 |
| $\sigma_H$ | 0.978 | 0.003 |
| $\sigma_G$ | 0.85 | 0.015 |

Table 3: Demand Parameter Estimates

main characteristics

| parameter | estimate | st dev | parameter | estimate | st dev |
|---|---|---|---|---|---|
| NetWaresmp | 0.161 | 0.022 | NTsmp | 0.224 | 0.033 |
| OS400smp | 0.247 | 0.046 | OS390smp | 1.586 | 0.100 |
| OpenVMSsmp | -0.451 | 0.052 | Unixsmp | 0.228 | 0.025 |
| Otherossmp | 0.215 | 0.022 | Unixmmp | 1.292 | 0.125 |
| NetWareup | 0.134 | 0.040 | NTup | 0.205 | 0.046 |
| OS400up | -0.220 | 0.056 | OS390up | 1.024 | 0.102 |
| OpenVMSup | -0.740 | 0.067 | Unixup | 0.112 | 0.042 |
| Otherosup | 0.144 | 0.036 | serversmp | 0.916 | 0.029 |
| CISCsmp | 2.770 | 0.049 | RISCsmp | 0.704 | 0.027 |
| ursmp | -0.009 | 0.001 | racksmp | 0.079 | 0.024 |
| ccapacsmp | 0.008 | 0.0003 | ccountsmp | 0.044 | 0.001 |
| CISCmmp | 2.908 | 0.644 | RISCmmp | 2.915 | 0.808 |
| ccapacmmp | 0.003 | 0.0003 | ccountmmp | 0.001 | 0.001 |
| serverup | 0.635 | 0.048 | CISCup | 0.355 | 0.049 |
| RISCup | -0.111 | 0.049 | urup | 0.011 | 0.007 |
| rackup | 0.214 | 0.075 | constant | -4.083 | 0.066 |

Note: All variables in Table 3 and 4 are interacted with either UP (up ending), or SMP (smp ending), or MMP (mmp ending). Variable names are explained in Appendix A and also in Table 1.

Table 3 (cont.): Demand Parameter Estimates

firm fixed effects

| parameter | estimate | st dev | parameter | estimate | st dev |
|---|---|---|---|---|---|
| acersmp | -0.160 | 0.060 | Amdalsmp | -0.628 | 0.075 |
| ASTsmp | -0.289 | 0.074 | copqsmp | -0.146 | 0.056 |
| Cprexsmp | 0.442 | 0.158 | Craysmp | -32.96 | 0.724 |
| dtgensmp | -0.342 | 0.061 | dellsmp | -0.125 | 0.057 |
| digismp | -0.687 | 0.060 | fujismp | 0.258 | 0.062 |
| Fujsimsmp | -0.054 | 0.060 | Gatwsmp | -0.224 | 0.058 |
| Bullsmp | -0.466 | 0.072 | hwpdsmp | 0.130 | 0.056 |
| Hitachsmp | -0.095 | 0.061 | ibmasmp | -0.292 | 0.056 |
| ICLsmp | -0.713 | 0.081 | Intgrsmp | -0.204 | 0.087 |
| Micronsmp | -0.112 | 0.065 | Mitsusmp | 0.022 | 0.064 |
| Motorsmp | -1.630 | 0.120 | NCRsmp | 0.115 | 0.060 |
| NECsmp | -0.052 | 0.056 | olivsmp | -0.128 | 0.064 |
| Othervendorsmp | -0.375 | 0.057 | Seqtsmp | 0.997 | 0.079 |
| silismp | 0.502 | 0.064 | Siemsmp | 0.037 | 0.058 |
| Stratsmp | 1.071 | 0.062 | suunsmp | -0.704 | 0.064 |
| Tandemsmp | -0.272 | 0.104 | Toshsmp | -0.294 | 0.062 |
| Unisyssmp | -0.018 | 0.058 | VaLinsmp | 0.020 | 0.129 |
| copqmmp | -3.490 | 0.819 | fujimmp | -5.715 | 0.846 |
| Fujsimmmp | -8.049 | 0.891 | hwpdmmp | -0.344 | 0.811 |
| Hitachmmp | -3.225 | 0.666 | ibmammp | -3.854 | 0.795 |
| ICLmmp | 1.617 | 0.997 | NECmmp | -2.623 | 0.833 |
| Othervendormmp | -4.533 | 0.795 | Siemmmp | -1.042 | 0.830 |
| Tandemmmp | -4.027 | 0.811 | acerup | 0.062 | 0.043 |
| Amdalup | -0.252 | 0.098 | apleup | 0.015 | 0.079 |
| ASTup | -0.134 | 0.075 | copqup | 0.036 | 0.031 |
| dtgenup | -0.320 | 0.064 | dellup | -0.123 | 0.070 |
| digiup | -0.175 | 0.035 | fujiup | 0.137 | 0.041 |

Table 3 (cont.): Demand Parameter Estimates

| parameter | estimate | st dev | parameter | estimate | st dev |
|---|---|---|---|---|---|
| Fujsimup | 0.058 | 0.053 | Gatwup | -0.162 | 0.098 |
| Bullup | 0.524 | 0.082 | hwpdup | -0.058 | 0.033 |
| Hitachup | -0.063 | 0.050 | ibmaup | 0.065 | 0.031 |
| Mitsuup | 0.313 | 0.042 | Motorup | -0.408 | 0.089 |
| NCRup | -0.004 | 0.066 | NECup | 0.157 | 0.035 |
| olivup | 0.077 | 0.048 | Siemup | 0.011 | 0.035 |
| suunup | -0.337 | 0.053 | Toshup | 0.970 | 0.054 |
| Unisysup | -0.118 | 0.085 | VaLinup | 0.257 | 0.179 |
| region dummies | | | | | |
| jasmp | 0.077 | 0.013 | ussmp | 0.706 | 0.010 |
| jammp | 0.514 | 0.082 | usmmp | 0.659 | 0.067 |
| jaup | 0.067 | 0.021 | usup | 0.564 | 0.017 |
| time dummies | | | | | |
| q296smp | 0.021 | 0.033 | q396smp | 0.105 | 0.032 |
| q496smp | 0.207 | 0.031 | q197smp | 0.188 | 0.031 |
| q297smp | 0.241 | 0.031 | q397smp | 0.397 | 0.031 |
| q497smp | 0.566 | 0.030 | q198smp | 0.464 | 0.030 |
| q298smp | 0.377 | 0.030 | q398smp | 0.451 | 0.030 |
| q498smp | 0.602 | 0.030 | q199smp | 0.501 | 0.030 |
| q299smp | 0.591 | 0.030 | q399smp | 0.603 | 0.031 |
| q499smp | 0.708 | 0.030 | q100smp | 0.745 | 0.031 |
| q200smp | 0.874 | 0.030 | q300smp | 0.912 | 0.030 |
| q400smp | 1.047 | 0.030 | q101smp | 0.921 | 0.031 |
| q296mmp | 0.705 | 0.155 | q396mmp | 0.918 | 0.152 |
| q496mmp | 1.272 | 0.149 | q197mmp | 1.538 | 0.149 |
| q297mmp | 1.135 | 0.157 | q397mmp | 0.695 | 0.161 |
| q497mmp | 0.465 | 0.174 | q198mmp | 0.518 | 0.159 |
| q298mmp | 0.234 | 0.159 | q398mmp | 0.616 | 0.168 |

Table 3 (cont.): Demand Parameter Estimates

| parameter | estimate | st dev | parameter | estimate | st dev |
|---|---|---|---|---|---|
| q498mmp | 1.390 | 0.165 | q199mmp | -0.767 | 0.196 |
| q299mmp | 0.394 | 0.173 | q399mmp | 0.257 | 0.183 |
| q499mmp | 0.407 | 0.181 | q100mmp | -0.245 | 0.189 |
| q200mmp | -0.539 | 0.177 | q300mmp | -0.028 | 0.179 |
| q400mmp | 0.911 | 0.176 | q101mmp | -0.834 | 0.184 |
| q296up | -0.041 | 0.038 | q396up | 0.089 | 0.038 |
| q496up | 0.201 | 0.038 | q197up | 0.225 | 0.038 |
| q297up | 0.236 | 0.038 | q397up | 0.319 | 0.038 |
| q497up | 0.408 | 0.038 | q198up | 0.326 | 0.039 |
| q298up | 0.103 | 0.040 | q398up | 0.287 | 0.042 |
| q498up | 0.458 | 0.043 | q199up | 0.324 | 0.043 |
| q299up | 0.361 | 0.042 | q399up | 0.388 | 0.044 |
| q499up | 0.530 | 0.045 | q100up | 0.526 | 0.047 |
| q200up | 0.633 | 0.050 | q300up | 0.671 | 0.051 |
| q400up | 0.877 | 0.049 | q101up | 0.762 | 0.052 |

## Table 4: Supply Parameter Estimates

main characteristics

| parameter | estimate | st dev | parameter | estimate | st dev |
|---|---|---|---|---|---|
| NetWaresmp | 0.005 | 0.003 | NTsmp | -0.004 | 0.003 |
| OS400smp | 0.019 | 0.008 | OS390smp | 0.203 | 0.008 |
| OpenVMSsmp | -0.033 | 0.007 | Unixsmp | 0.007 | 0.003 |
| Otherossmp | 0.029 | 0.004 | Unixmmp | 0.190 | 0.022 |
| NetWareup | -0.009 | 0.007 | NTup | -0.012 | 0.006 |
| OS400up | -0.015 | 0.010 | OS390up | 0.161 | 0.010 |
| OpenVMSup | -0.044 | 0.011 | Unixup | -0.012 | 0.007 |
| Otherosup | 0.008 | 0.007 | serversmp | 0.092 | 0.005 |
| CISCsmp | 0.261 | 0.006 | RISCsmp | 0.063 | 0.005 |
| ursmp | -0.001 | 0.0003 | racksmp | -0.006 | 0.004 |
| ccapacsmp | 0.001 | 0.0001 | ccountsmp | 0.004 | 0.0002 |
| CISCmmp | 0.413 | 0.117 | RISCmmp | 0.350 | 0.147 |
| ccapacmmp | 0.001 | 0.0001 | ccountmmp | -0.0002 | 0.0001 |
| serverup | 0.068 | 0.009 | CISCup | 0.015 | 0.009 |
| RISCup | -0.022 | 0.009 | urup | 0.0004 | 0.001 |
| rackup | 0.004 | 0.014 | constant | 0.026 | 0.008 |

firm fixed effects

| | | | | | |
|---|---|---|---|---|---|
| acersmp | -0.020 | 0.011 | Amdalsmp | -0.063 | 0.014 |
| ASTsmp | -0.025 | 0.013 | copqsmp | -0.022 | 0.010 |
| Cprexsmp | 0.046 | 0.029 | Craysmp | -3.085 | 0.109 |
| dtgensmp | -0.034 | 0.011 | dellsmp | -0.020 | 0.010 |
| digismp | -0.071 | 0.011 | fujismp | 0.014 | 0.011 |
| Fujsimsmp | -0.005 | 0.011 | Gatwsmp | -0.026 | 0.010 |
| Bullsmp | -0.052 | 0.013 | hwpdsmp | 0.004 | 0.010 |
| Hitachsmp | -0.016 | 0.011 | ibmasmp | -0.036 | 0.010 |
| ICLsmp | -0.075 | 0.015 | Intgrsmp | -0.024 | 0.016 |
| Micronsmp | -0.021 | 0.012 | Mitsusmp | -0.007 | 0.012 |

Table 4 (cont.): Supply Parameter Estimates

| parameter | estimate | st dev | parameter | estimate | st dev |
|---|---|---|---|---|---|
| Motorsmp | -0.164 | 0.022 | NCRsmp | 0.004 | 0.011 |
| NECsmp | -0.012 | 0.010 | olivsmp | -0.019 | 0.012 |
| Othervendorsmp | -0.042 | 0.010 | Seqtsmp | 0.088 | 0.014 |
| silismp | 0.039 | 0.012 | Siemsmp | -0.005 | 0.010 |
| Stratsmp | 0.103 | 0.011 | suunsmp | -0.079 | 0.011 |
| Tandemsmp | -0.028 | 0.019 | Toshsmp | -0.034 | 0.011 |
| Unisyssmp | -0.009 | 0.011 | VaLinsmp | -0.014 | 0.023 |
| copqmmp | -0.167 | 0.149 | fujimmp | -0.524 | 0.154 |
| Fujsimmmp | -0.865 | 0.161 | hwpdmmp | 0.027 | 0.148 |
| Hitachmmp | -0.248 | 0.121 | ibmammp | -0.292 | 0.145 |
| ICLmmp | 0.209 | 0.182 | NECmmp | -0.226 | 0.152 |
| Othervendormmp | -0.310 | 0.145 | Siemmmp | -0.012 | 0.151 |
| Tandemmmp | -0.190 | 0.148 | acerup | 0.002 | 0.008 |
| Amdalup | -0.027 | 0.018 | apleup | 0.005 | 0.014 |
| ASTup | -0.006 | 0.014 | copqup | -0.002 | 0.006 |
| dtgenup | -0.015 | 0.012 | dellup | -0.008 | 0.013 |
| digiup | -0.018 | 0.006 | fujiup | 0.003 | 0.007 |
| Fujsimup | 0.012 | 0.010 | Gatwup | -0.011 | 0.018 |
| Bullup | 0.057 | 0.015 | hwpdup | -0.008 | 0.006 |
| Hitachup | -0.010 | 0.009 | ibmaup | 0.003 | 0.006 |
| Mitsuup | 0.024 | 0.008 | Motorup | -0.032 | 0.016 |
| NCRup | 0.001 | 0.012 | NECup | 0.010 | 0.006 |
| olivup | 0.004 | 0.009 | Siemup | 0.001 | 0.006 |
| suunup | -0.034 | 0.009 | Toshup | 0.083 | 0.010 |
| Unisysup | -0.012 | 0.015 | VaLinup | -0.001 | 0.033 |

Table 4 (cont.): Supply Parameter Estimates

region dummies

| parameter | estimate | st dev | parameter | estimate | st dev |
|---|---|---|---|---|---|
| jasmp | 0.015 | 0.002 | ussmp | -0.003 | 0.002 |
| jammp | 0.046 | 0.015 | usmmp | -0.015 | 0.012 |
| jaup | 0.015 | 0.004 | usup | -0.004 | 0.003 |
| time dummies | | | | | |
| q296smp | -0.0001 | 0.006 | q396smp | 0.001 | 0.006 |
| q496smp | -0.008 | 0.006 | q197smp | -0.011 | 0.006 |
| q297smp | -0.010 | 0.006 | q397smp | -0.007 | 0.006 |
| q497smp | -0.006 | 0.005 | q198smp | -0.013 | 0.005 |
| q298smp | -0.008 | 0.005 | q398smp | -0.014 | 0.005 |
| q498smp | -0.021 | 0.005 | q199smp | -0.017 | 0.005 |
| q299smp | -0.017 | 0.005 | q399smp | -0.012 | 0.005 |
| q499smp | -0.012 | 0.005 | q100smp | -0.008 | 0.005 |
| q200smp | -0.004 | 0.005 | q300smp | -0.007 | 0.005 |
| q400smp | -0.009 | 0.005 | q101smp | -0.010 | 0.005 |
| q296mmp | 0.127 | 0.028 | q396mmp | 0.138 | 0.028 |
| q496mmp | 0.134 | 0.027 | q197mmp | 0.145 | 0.027 |
| q297mmp | 0.104 | 0.028 | q397mmp | 0.100 | 0.029 |
| q497mmp | 0.083 | 0.032 | q198mmp | 0.141 | 0.029 |
| q298mmp | 0.104 | 0.029 | q398mmp | 0.139 | 0.030 |
| q498mmp | 0.170 | 0.030 | q199mmp | 0.080 | 0.036 |
| q299mmp | 0.195 | 0.031 | q399mmp | 0.187 | 0.033 |
| q499mmp | 0.151 | 0.033 | q100mmp | 0.146 | 0.034 |
| q200mmp | 0.118 | 0.032 | q300mmp | 0.136 | 0.033 |
| q400mmp | 0.200 | 0.032 | q101mmp | 0.120 | 0.033 |
| q296up | -0.007 | 0.007 | q396up | -0.003 | 0.007 |
| q496up | -0.009 | 0.007 | q197up | -0.008 | 0.007 |
| q297up | -0.010 | 0.007 | q397up | -0.015 | 0.007 |

Table 4 (cont.): Supply Parameter Estimates

| parameter | estimate | st dev | parameter | estimate | st dev |
|---|---|---|---|---|---|
| q497up | -0.019 | 0.007 | q198up | -0.023 | 0.007 |
| q298up | -0.031 | 0.007 | q398up | -0.028 | 0.008 |
| q498up | -0.030 | 0.008 | q199up | -0.031 | 0.008 |
| q299up | -0.031 | 0.008 | q399up | -0.027 | 0.008 |
| q499up | -0.025 | 0.008 | q100up | -0.025 | 0.008 |
| q200up | -0.022 | 0.009 | q300up | -0.025 | 0.009 |
| q400up | -0.024 | 0.009 | q101up | -0.027 | 0.009 |

## C.2 Simulation results

Table 5: SSNIP Test for U.S. (1st Quarter, 2001) - 5% Price increase

| lower price limit ($) | upper price limit ($) | # of products | % change in profits ($\triangle\pi_M^{ssnip}$ ) |
|---|---|---|---|
| 0 | 2000 | 31 | -0.4 |
| 0 | 3000 | 65 | -0.2 |
| 0 | 4000 | 132 | 1.4 |
| 4000 | 5000 | 63 | -0.7 |
| 4000 | 6000 | 111 | -0.1 |
| 4000 | 7000 | 121 | 0.0 |
| 4000 | 8000 | 140 | 0.2 |
| 8000 | 9000 | 12 | -10.1 |
| 8000 | 10000 | 41 | -6.1 |
| ... | ... | ... | ... |
| 8000 | 900000 | 303 | 4.7 |

Table 6: SSNIP Test for Europe (1st Quarter, 2001) - 5% Price increase

| lower price limit ($) | upper price limit ($) | # of products | % change in profits ($\triangle\pi_M^{ssnip}$) |
|---|---|---|---|
| 0 | 2000 | 27 | -0.4 |
| 0 | 3000 | 55 | -0.4 |
| 0 | 4000 | 123 | 1.2 |
| 4000 | 5000 | 58 | -2.1 |
| 4000 | 6000 | 112 | -0.2 |
| 4000 | 7000 | 134 | -0.1 |
| 4000 | 8000 | 166 | 0.3 |
| 8000 | 9000 | 25 | -6.7 |
| 8000 | 10000 | 63 | -4.6 |
| ... | ... | ... | ... |
| 8000 | 390000 | 25 | -6.7 |
| 8000 | 400000 | 311 | 1.0 |
| 400000 | 1000000 | 24 | -99.9 |

Table 7: SSNIP Test for Japan (1st Quarter, 2001) - 5% Price increase

| lower price limit ($) | upper price limit ($) | # of products | % change in profits ($\triangle\pi_M^{ssnip}$) |
|---:|---:|---:|---:|
| 0 | 2000 | 17 | -0.1 |
| 0 | 3000 | 27 | 0.005 |
| 3000 | 4000 | 50 | 1.1 |
| 4000 | 5000 | 44 | -1.1 |
| 4000 | 6000 | 65 | -0.8 |
| 4000 | 7000 | 82 | -0.3 |
| 4000 | 8000 | 107 | 1.1 |
| 8000 | 9000 | 12 | -5.4 |
| 8000 | 10000 | 25 | -4.8 |
| ... | ... | ... | ... |
| 8000 | 79000 | 163 | -0.7 |
| 8000 | 80000 | 164 | 0.9 |
| 80000 | 1000000 | 65 | -80.6 |

Table 8: SSNIP Test for U.S. (1st Quarter, 2001) - 10% Price increase

| lower price limit ($) | upper price limit ($) | # of products | % change in profits ($\triangle\pi_M^{ssnip}$) |
|---:|---:|---:|---:|
| 0 | 2000 | 31 | -0.9 |
| 0 | 3000 | 65 | -0.6 |
| 0 | 4000 | 132 | 2.4 |
| 4000 | 5000 | 63 | -2.0 |
| 4000 | 6000 | 111 | -1.1 |
| 4000 | 7000 | 121 | -0.9 |
| 4000 | 8000 | 140 | -0.6 |
| 4000 | 9000 | 152 | -0.8 |
| 4000 | 10000 | 181 | 0.7 |
| 10000 | 11000 | 6 | -8.5 |
| 10000 | 12000 | 31 | -12.9 |
| ... | ... | ... | ... |
| 10000 | 1000000 | 264 | -8.4 |

Table 9: SSNIP Test for Europe (1st Quarter, 2001) - 10% Price increase

| lower price limit ($) | upper price limit ($) | # of products | % change in profits ($\triangle\pi_M^{ssnip}$) |
|---:|---:|---:|---:|
| 0 | 2000 | 27 | -1.2 |
| 0 | 3000 | 55 | -1.5 |
| 0 | 4000 | 123 | 1.7 |
| 4000 | 5000 | 58 | -5.6 |
| 4000 | 6000 | 112 | -2.1 |
| 4000 | 7000 | 134 | -2.0 |
| 4000 | 8000 | 166 | -1.2 |
| 4000 | 9000 | 191 | -0.3 |
| 4000 | 10000 | 229 | 2.6 |
| 10000 | 12000 | 21 | -24.7 |
| ... | ... | ... | ... |
| 10000 | 1000000 | 272 | -10.1 |

Table 10: SSNIP Test for Japan (1st Quarter, 2001) - 10% Price increase

| lower price limit ($) | upper price limit ($) | # of products | % change in profits ($\triangle\pi_M^{ssnip}$) |
|---:|---:|---:|---:|
| 0 | 2000 | 17 | -0.5 |
| 0 | 3000 | 27 | -0.3 |
| 0 | 4000 | 77 | 3.6 |
| 4000 | 5000 | 44 | -4.0 |
| 4000 | 6000 | 65 | -3.4 |
| 4000 | 7000 | 82 | -2.5 |
| 4000 | 8000 | 107 | -0.1 |
| 4000 | 9000 | 119 | 1.1 |
| 9000 | 10000 | 13 | -15.8 |
| ... | ... | ... | ... |
| 9000 | 900000 | 213 | -0.5 |
| 9000 | 1000000 | 217 | 1.7 |

Table 11: FERM test, U.S. (1st Quarter, 2001): ERMP Index, 10% threshold

| lower limit ($) | upper limit ($) | # of prods | % av. price chng ($\Delta p_M$) |
|---|---|---|---|
| 0 | 2000 | 31 | 5.6 |
| 0 | 3000 | 65 | 10.5 |
| 3000 | 4000 | 67 | 18.8 |
| 4000 | 5000 | 63 | 8.1 |
| 4000 | 6000 | 111 | 13.0 |
| 6000 | 7000 | 10 | 0.2 |
| ... | ... | ... | ... |
| 6000 | 100000 | 280 | 9.9 |
| 6000 | 110000 | 281 | 10.0 |
| 110000 | 120000 | 3 | -0.001 |
| ... | ... | ... | ... |
| 110000 | 900000 | 51 | 1.3 |
| 110000 | 1000000 | 53 | 1.5 |

Table 12: FERM Test, Europe (1st Quarter, 2001): ERMP Index, 10% threshold

| lower limit ($) | upper limit ($) | # of prods | % av. price chng ($\Delta p_M$) |
|---|---|---|---|
| 0 | 2000 | 27 | 4.3 |
| 0 | 3000 | 55 | 7.6 |
| 0 | 4000 | 123 | 29.1 |
| 4000 | 5000 | 58 | 5.1 |
| 4000 | 6000 | 112 | 11.0 |
| 6000 | 7000 | 22 | 0.2 |
| ... | ... | ... | ... |
| 6000 | 300000 | 357 | 9.8 |
| 6000 | 400000 | 365 | 10.4 |
| 400000 | 500000 | 9 | 0.004 |
| ... | ... | ... | ... |
| 400000 | 1000000 | 24 | 0.2 |

Table 13: FERM test, Japan (1st Quarter, 2001): ERMP Index, 10% threshold

| lower limit ($) | upper limit ($) | # of prods | % av. price chng ($\Delta p_M$) |
|---:|---:|---:|---:|
| 0 | 2000 | 17 | 9.3 |
| 0 | 3000 | 27 | 10.0 |
| 0 | 4000 | 77 | 42.6 |
| 4000 | 5000 | 44 | 3.2 |
| 4000 | 6000 | 65 | 4.9 |
| 4000 | 7000 | 82 | 6.8 |
| 4000 | 8000 | 107 | 11.7 |
| 8000 | 9000 | 12 | 0.4 |
| ... | ... | ... | ... |
| 8000 | 900000 | 225 | 8.1 |
| 8000 | 1000000 | 229 | 8.3 |

Table 14: FERM test, U.S. (1st Quarter, 2001): ERMP Index, 15% threshold

| lower limit ($) | upper limit ($) | # of prods | % rel. cons.surp. chng ($\Delta cs_M$) |
|---:|---:|---:|---:|
| 0 | 2000 | 31 | -4.1 |
| 0 | 3000 | 65 | -8.9 |
| 0 | 4000 | 132 | -34.9 |
| 4000 | 5000 | 63 | -11.0 |
| 4000 | 6000 | 111 | -17.8 |
| 6000 | 7000 | 10 | -0.5 |
| ... | ... | ... | ... |
| 6000 | 14000 | 114 | -14.6 |
| 6000 | 15000 | 125 | -16.2 |
| 15000 | 16000 | 5 | 0.0 |
| ... | ... | ... | ... |
| 15000 | 200000 | 168 | -14.6 |
| 15000 | 300000 | 178 | -15.0 |
| 300000 | 400000 | 6 | -1.4 |
| ... | ... | ... | ... |
| 800000 | 900000 | 2 | -0.004 |
| 800000 | 1000000 | 4 | -0.004 |

Table 15: FERM test, Europe (1st Quarter, 2001): ERMP Index, 15% threshold

| lower limit ($) | upper limit ($) | # of prods | % rel. cons.surp. chng ($\Delta cs_M$) |
|---|---|---|---|
| 0 | 2000 | 27 | -4.9 |
| 0 | 3000 | 55 | -9.9 |
| 0 | 4000 | 123 | -30.1 |
| 4000 | 5000 | 58 | -11.2 |
| 4000 | 6000 | 112 | -21.2 |
| 6000 | 7000 | 22 | -0.5 |
| ... | ... | ... | ... |
| 6000 | 13000 | 142 | -16.0 |
| 13000 | 14000 | 9 | -0.04 |
| ... | ... | ... | ... |
| 13000 | 79000 | 178 | -15.2 |
| 79000 | 80000 | 1 | 0.0 |
| ... | ... | ... | ... |
| 79000 | 800000 | 67 | -22.1 |
| 800000 | 1000000 | 2 | -0.002 |

Table 16: FERM Test, Japan (1st Quarter, 2001): ERMP Index, 15% threshold

| lower limit ($) | upper limit ($) | # of prods | % rel. cons.surp. chng ($\Delta cs_M$) |
|---|---|---|---|
| 0 | 2000 | 17 | -8.1 |
| 0 | 3000 | 27 | -9.5 |
| 0 | 4000 | 77 | -37.8 |
| 4000 | 5000 | 44 | -8.3 |
| 4000 | 6000 | 65 | -12.0 |
| 4000 | 7000 | 82 | -16.2 |
| 7000 | 8000 | 25 | -6.7 |
| ... | ... | ... | ... |
| 7000 | 11000 | 53 | -18.3 |
| 11000 | 12000 | 12 | -2.1 |
| ... | ... | ... | ... |
| 11000 | 25000 | 77 | -15.3 |
| 25000 | 26000 | 3 | -0.01 |
| ... | ... | ... | ... |
| 25000 | 89000 | 64 | -15.0 |
| 89000 | 1000000 | 60 | -28.8 |

Table 17: Summary: Relevant Markets (in dollars), US (1st Quarter, 2001)

| SSNIP 5% | SSNIP 10% | FERM ERMP | FERM ERMC |
|---|---|---|---|
| 0 - 4000 | 0 - 4000 | 0 - 3000 | 0 - 4000 |
| 4000 - 8000 | 4000 - 10000 | 3000 - 4000 | 4000 - 6000 |
| 8000 - 900000 | | 4000 - 6000 | 6000 - 15000 |
| | | 6000 - 110000 | 15000 - 300000 |

*Data:* SSNIP 5%: Table 5; SSNIP 10%: Table 8; FERM ERMP: Table 11; FERM ERMC: Table 14.

Table 18: Summary: Relevant Markets (in dollars), Europe (1st Quarter, 2001)

| SSNIP 5% | SSNIP 10% | FERM ERMP | FERM ERMC |
|---|---|---|---|
| 0 - 4000 | 0 - 4000 | 0 - 4000 | 0 - 4000 |
| 4000 - 8000 | 4000 - 10000 | 4000 - 6000 | 4000 - 6000 |
| 8000 - 400000 | | 6000 - 400000 | 6000 - 13000 |
| | | 400000 - 1000000 | 13000 - 79000 |
| | | | 79000 - 800000 |

*Data:* SSNIP 5%: Table 6; SSNIP 10%: Table 9; FERM ERMP: Table 12; FERM ERMC: Table 15.

Table 19: Summary: Relevant Markets (in dollars), Japan (1st Quarter, 2001)

| SSNIP 5% | SSNIP 10% | FERM ERMP | FERM ERMC |
|---|---|---|---|
| 0 - 3000 | 0 - 4000 | 0 - 4000 | 0 - 4000 |
| 3000 - 4000 | 4000 - 9000 | 4000 - 8000 | 4000 - 7000 |
| 4000 - 8000 | 9000 - 1000000 | | 7000 - 11000 |
| 8000 - 80000 | | | 11000 - 25000 |
| | | | 25000 - 89000 |
| | | | 89000 - 1000000 |

*Data:* SSNIP 5%: Table 7; SSNIP 10%: Table 10; FERM ERMP: Table 13; FERM ERMC: Table 16.

# D Figures

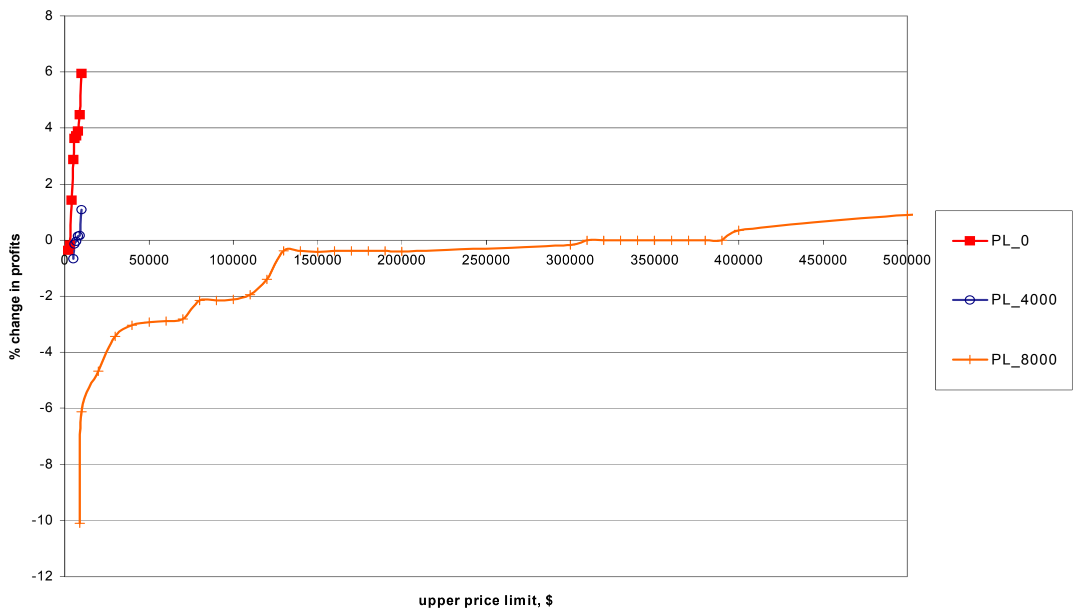


Figure 1: SSNIP Test for U.S. (1st Quarter, 2001) - 5% Price increase

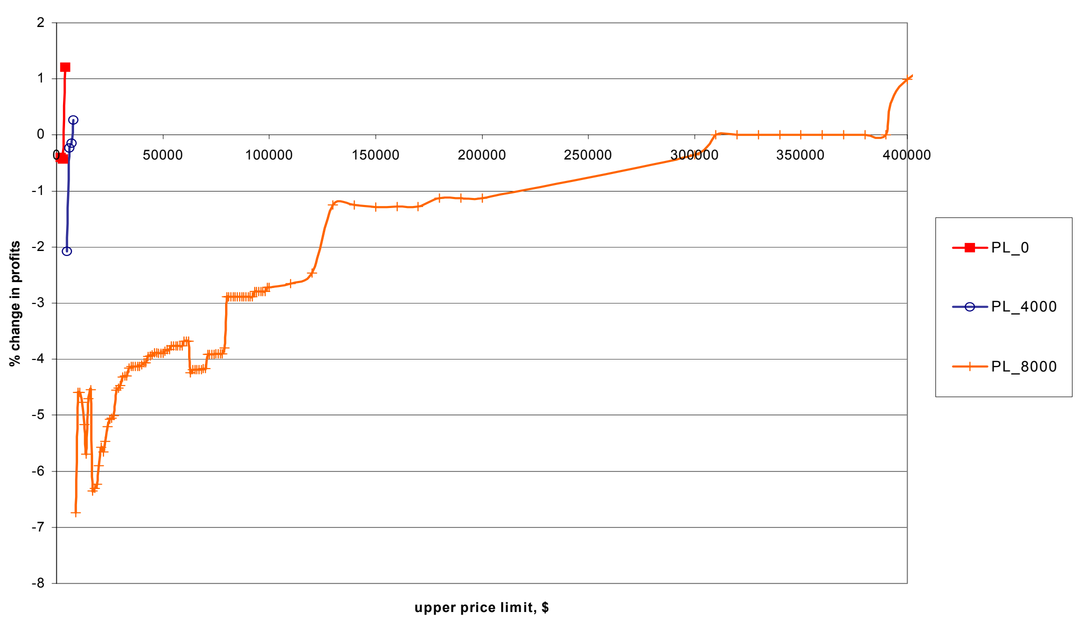


Figure 2: SSNIP Test for Europe (1st Quarter, 2001) - 5% Price increase

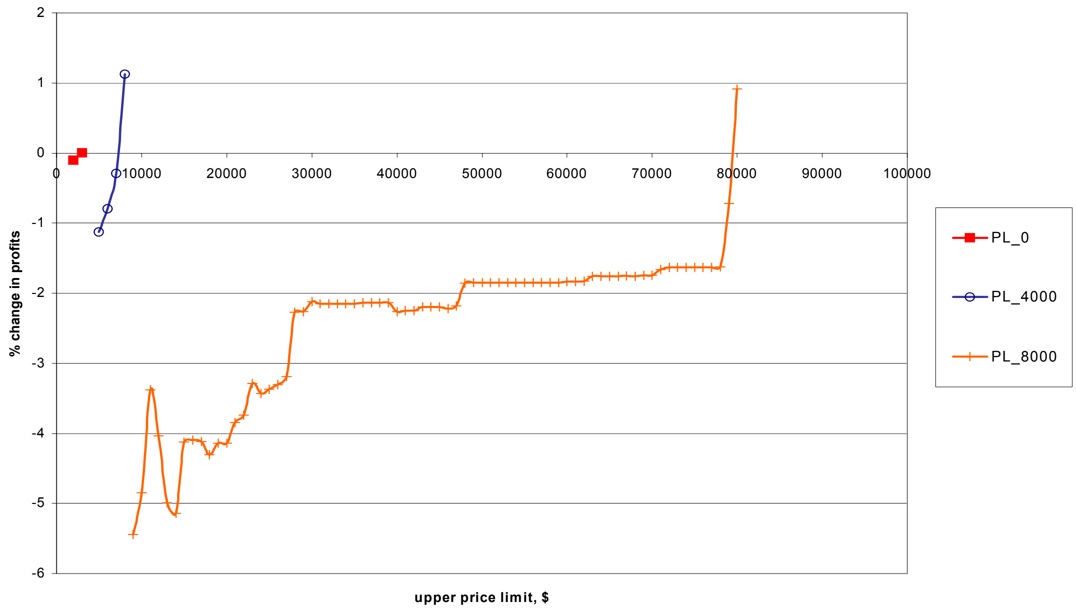


FIGURE 3: SSNIP TEST FOR JAPAN (1ST QUARTER, 2001) - 5% PRICE INCREASE

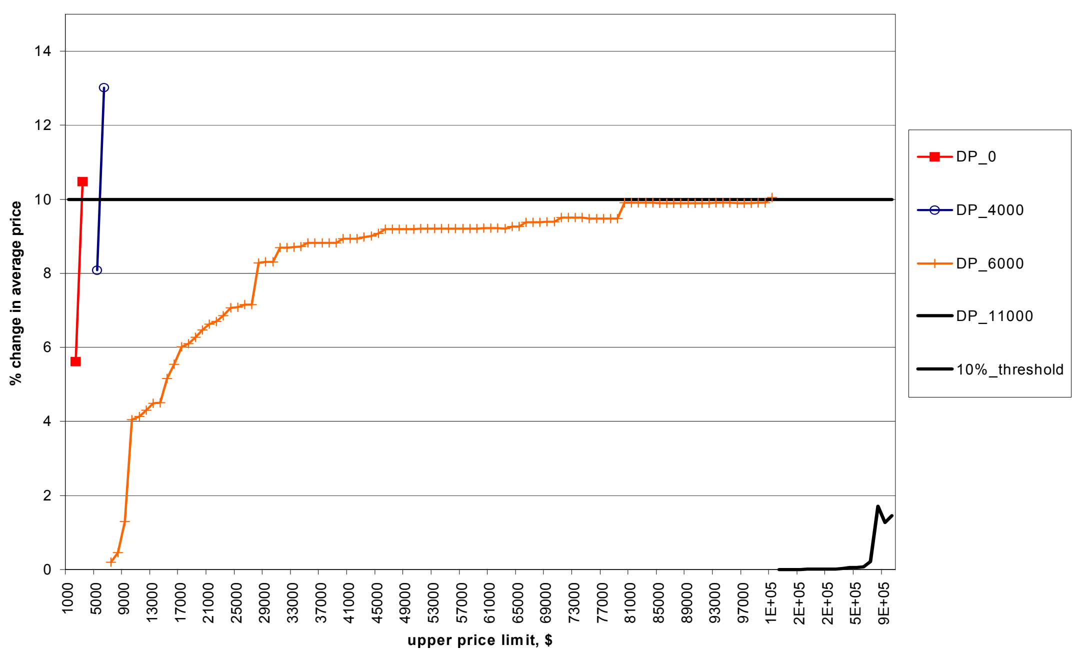


FIGURE 4: FERM TEST, U.S. (1ST QUARTER, 2001): ERMP INDEX, 10% THRESHOLD

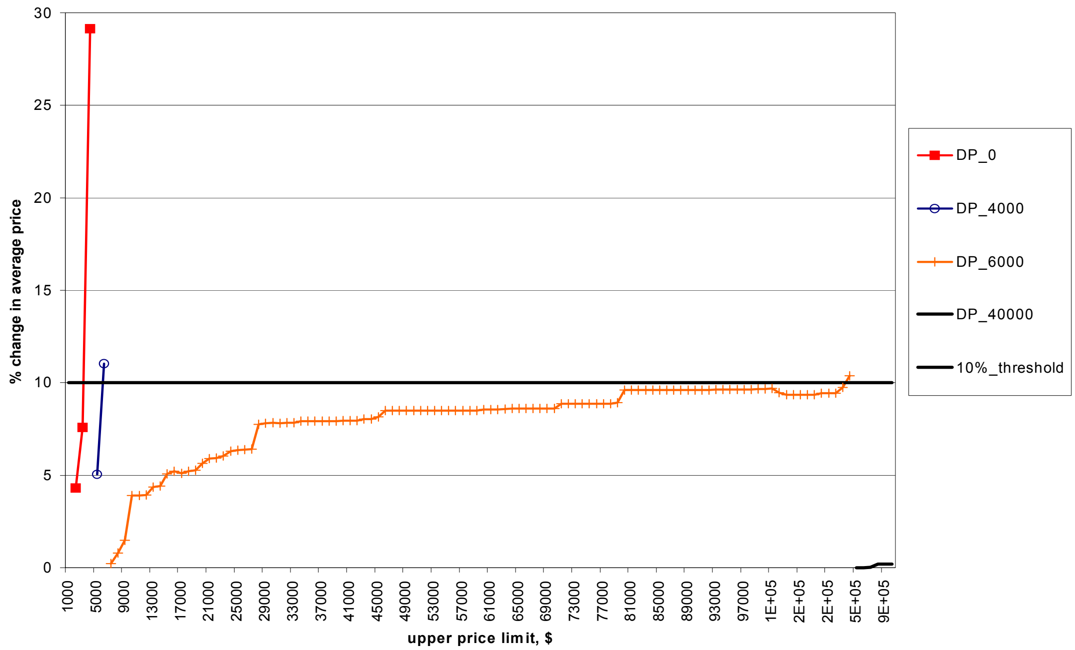


Figure 5: FERM test, Europe (1st Quarter, 2001): ERMP Index, 10% threshold

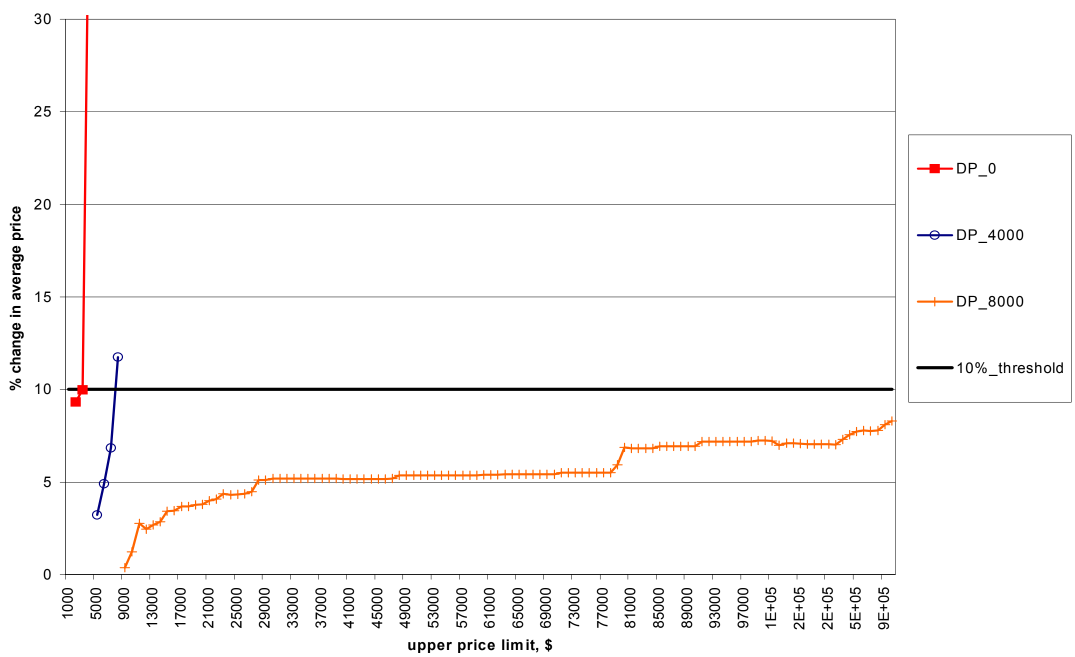


Figure 6: FERM test, Japan (1st Quarter, 2001): ERMP Index, 10% threshold

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