

**Technological Disequilibrium:
Measuring Technological Change in Local Area Networks Equipment**

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Abstract

Technological change can affect existing products very rapidly and at an uneven pace depending on the type and on the age of an industry. In young and fast growing industries, the process of technological change usually entails a series of improvements in existing products that affect their technological characteristics. Depending on the type and timing of innovation, prices may reflect or not the technological change to their characteristics. This paper is an attempt to address the issue of the relationships between technological improvements in characteristics and the extent of creation of economic benefits following from these improvements in the specific case of hub equipment for Local Area Networks (LANs). It pursues this aim by using a constant-quality price index constructed from hedonic price regressions. This paper argues that it may be that economic benefits from technological improvements entailing an extension in the characteristics of hub equipment may not be captured by an overall constant-quality price index. Although the issue of identification of a better methodology to assess the extent of economic benefits is not explicitly addressed in this paper, some related questions are addressed, for instance: What is the extent of the economic benefits from technological improvement that can be captured with the use of a constant-quality price indexes? Have these economic benefits from technological improvements been equally distributed across each characteristic? Has the rate of growth of economic benefits occurred evenly over time?

JEL Classification: O30, L63

Introduction

Technological change can affect existing products very rapidly and at an uneven pace depending on the type and on the age of an industry. In young and fast growing industries, the process of technological change usually entails a series of improvements in existing products that affect their technological characteristics. In some cases, improvements have to occur continuously because products must maintain compatibility in order to be integrated into an existing installed base of older products which, for either economic or for technological reasons, cannot be completely scrapped and substituted by the new ones. In other cases, a series of subsequent innovations in some of the characteristics is necessary to extend the applicability of new products. Moreover, as the characteristics of new products become familiar to adopters, better ways of using new products are developed. This feeds back into decisions about the type and extent of new technological improvements necessary to meet the increased applicability. As a result of this co-evolutionary process, different product characteristics can be affected unevenly and at different points in time by technological change. Depending on the type and timing of innovation, prices may reflect or not the technological change to their characteristics.

Hub equipment, the object of investigation in this paper, constitutes the infrastructure that enables computers, other types of end stations and/or peripherals, to be linked together in order to form a Local Area Network (LAN) connecting different users within an area of relatively narrow extension such as university campus or different buildings on a company site. In particular, hub equipment is necessary to extend the network and to ensure that data transmission occurs among end users.

Hub equipment over the last decade has undergone very rapid and continuous technological change. Technical improvements were induced both by the desire of users to cope with the pressure arising from the introduction in existing LANs of new end stations with higher computing speed and larger memories and also in order to enable users to extend their LANs by adding new end stations to existing ones. Technological improvements occurred to many characteristics. One of these characteristics was the type of technological standard supported by the piece of equipment. Technological standards set both the 'rules' and the speed at which data transmission occurs. Both the timing and extent to which technological change in a standard occurred depended on the outcome of 'de jure' processes of endorsement of formal technical proposals submitted to standardisation committees by individual producers and/or consortia. The official endorsement of new standards usually implied an increase in the speed of data transmission and/or a modification of the data encoding system. It was not always the case that existing equipment could accommodate these modifications. Most of the time improvements that involved changes in product design were

required. When equipment had to be improved to support new standards and to integrate them within existing LAN infrastructures, the extent of technological change could be assessed by measuring the extent of improvements in the capacity of the hub equipment to receive and forward data.

This paper is an attempt to address the issue of the relationships between technological improvements in hub characteristics and the extent of creation of economic benefits following from these improvements. It pursues this aim by using a constant-quality price index constructed from hedonic price regressions. This paper argues that it may be that economic benefits from technological improvements entailing an extension in the characteristics of hub equipment may not be captured by an overall constant-quality price index. Although the issue of identification of a better methodology to assess the extent of economic benefits is not explicitly addressed in this paper, some related questions are addressed, for instance: What is the extent of the economic benefits from technological improvement that can be captured with the use of a constant-quality price indexes? Have these economic benefits from technological improvements been equally distributed across each characteristic? Has the rate of growth of economic benefits occurred evenly over time?

Answering these questions requires an extension of the constant-quality framework. This paper follows very closely the methodology introduced by Dulberger (Dulberger 1989) for the estimation of a constant-quality price index in those cases where in which technological improvements may entail the introduction of new capabilities in existing products at different points in time. This paper argues that this extension is particularly suitable to the case of hub equipment because technological improvements have occurred both along several technological characteristics and in a particular time sequence that has configured a sort of cyclical regular pattern of product updating.

The application of this extended framework enables us to measure the extent of economic benefits from technological improvements in product characteristics. Moreover, it will allow us to measure the extent to which technological improvement in product characteristics had induced a situation of 'technological disequilibrium' in the market for hub equipment.

Finally, with regard to the extent to which 'technological disequilibrium' is related to the introduction of new characteristics rather than to a modification of existing ones, the extended framework enables us to reach conclusions on the measurement of economic benefits from the

extension of the capabilities of existing products as opposed to the creation of economic benefits from improvements to existing characteristics.

The paper is organised as follows. Section 1 reviews the main features of the process of technological change in hub equipment in the 1990-1999 period. Section 2 outlines the methodology that is applied in the paper. Section 3 describes the data that are used for empirical investigation. Results are presented and commented on in Section 4, while conclusions are put forward in Section 5.

Section 1: Technological Change and the Creation of Economic Benefits in Hub Equipment, 1990-1999

The aim of this section is to describe briefly the important features of technological change in the market for hubs from 1990 to 1999. During this period, there was both a decline in price and an extension of the capabilities of hubs.

In the long term, hubs have undergone a decline in the cost, usually measured by the price per hub port, of connecting additional end stations to existing LANs. The important issue here is whether there is a relationship between the decline in port price and improvements in the technological characteristics of hubs, and whether changes in per port price can be associated with the introduction of particular products and/or to other market events. One possibility is that a clear pattern of improvement can be identified by comparing different generations of hubs. Another possibility is that hubs belonging to different generations are substitutes for one another and the prices of old and new generations do not follow a simple pattern. One of the reasons why the price may not follow a simple pattern in the latter case is the possibility that the price of hubs has been influenced by market disequilibrium. This case is typical of markets characterised by rapid technological change as has already been stressed in some studies of the technical change in computer equipment (Fisher, McGowan et al. 1983; Dulberger 1989). The interpretation of the pattern of decline in per port price depends on which of the two possibilities is embraced.

However, decline in the per port price of the equipment is only one of the dimensions along which hubs have been affected by technological change. Hubs also underwent an extension to their capabilities which occurred along many dimensions. First, new standards were introduced. New standards implemented different access schemes¹ and enabled hubs to transmit packets of data at higher speed than existing products. As a consequence of these features new hubs were able to cope

with the pressures put upon existing LANs by the adoption of end stations, both PCs and workstations, with faster computing capabilities and larger memories. Second, hubs were made 'stackable'. By tying more standalone hubs through the use of an external common backplane², the increased number of end stations attached over the LAN could be accommodated. Third, modularity of products was introduced. Modular hubs enabled users to mix and match modules of different density and standards. Modularity increased the flexibility of hubs to cope with both the growth of in number of existing end stations and with the increasing need of some users to transmit audio and video files which required higher speeds of transmission and steady data flows. Scientists and engineers were among the first to take advantage of the features of these modular multi-standard products.

While some of the new capabilities were associated with a change in the capability of equipment to support a certain number of users (i.e. changes along the density dimension), some new features were associated with the capability of equipment to transmit data to and from attached end stations. The latter were realised through changes in the design of products' backplanes. Products supporting multiple shared-media backplane segments within a single piece of equipment (multi-segment hubs) were introduced to enable equipment to support multiple segments of users and to increase, within one hub, the capability to support a higher number of end stations. Further improvements along this line were then achieved, first by modifying the backplane in order to make possible the communication between end stations attached to different segments (port switched or port-reconfiguration hubs), second by further segmenting the backplane, a procedure known as 'micro-segmentation', to reduce the number of active end stations down to just one per segment (switching hubs). These improvements in backplane design enabled users to overcome those problems of bandwidth allocation created by an increase both in the number and in the speed and memory of end stations attached to a shared backplane. These improvements took place in the 1990s at different points in time, being concentrated mostly in the first half and diffusing widely in the second half.

Finally, other extensions involved the deployment of new software in hub equipment. Software innovations improved the capability of hubs to manage data flows to and from end stations thereby enabling network managers to monitor and control data traffic, identify and isolate faults whenever they occurred, and reduce network downtimes. Moreover, software applications have been also used to introduce additional backplane capabilities, such as establishing a connection between

¹ Since the LAN media is to be shared by numerous PC users, then there must be some way to control access by multiple users to that media. An access scheme defines the media sharing methods (Goldman, J. (1997).)

different backplane segments, which, in some cases, could have taken longer to be implemented via hardware. These extensions made it easier to link different LAN segments together especially to those users who had experienced a chaotic and inconsistent growth in their LAN environment in the past which would have made the deployment of new hardware expensive. Software extensions are very important although sometimes less easy to measure than innovations which involving changes in the hardware.

The pace at which both technological improvements and new products were appearing conditioned the behaviour of users. Users who wanted to update their LANs had a variety of options. First, users could deploy in their LANs end stations with larger memories and higher speeds without having to improve other parts of their networks. Second, users could adopt new standards which had been already officially endorsed by standardisation committees or which had become available on the market, without updating their LAN equipment. As already experienced in other IT related markets (Greenstein 1997), technological disequilibrium among the components of the system, which opened up new technological opportunities for users, was inducing users to learn about their needs, plan for them, learn to expect further changes and continually to revise their situations.

Technological disequilibrium gave rise to a sort of cyclical regularity according to which: improvements in end stations by putting pressures on existing LAN structures created bottlenecks, which triggered the introduction of new high speed standard to alleviate the bottlenecks, which, in turn, required improvements to hub equipment in order for new standards to be integrated into existing LAN systems.

The economic features of this cycle were the following. First, the possibility to extend existing LANs by increasing the number of end stations that could be linked together became conditional on the occurrence of improvements in other system components. Demand for high speed standards reflected the desire of users to increase the number of end stations attached to the LAN. The possibility to deploy high speed standards became conditional on enhancements in the backplane capacity of hubs. Demand for hubs with higher capacity backplanes reflected the desire of users to adopt faster standards while increasing, or at least not decreasing, the unit of bandwidth allocated to each end station.

Second, improvements which took place in several components of the system translated into different types of economic benefits to hub users. On the one hand, increases in the port density of

² Within any LAN equipment, the path between the individual ports is provided via a connection between the input and

hubs necessary to integrate additional end stations might entail a decrease in per port price but also might involve a decrease in the unit of bandwidth allocated to each end station if not accompanied by other changes. In this case, the extent of the economic benefits to hub users would decrease. On the other hand, demand for higher speed standards could entail a decrease in the cost per unit of bandwidth, measured as the price per port per unit of bandwidth, allocated to each end station while decreasing, or at least not increasing, the per port price. In this case, the extent of economic benefits to hub users could exceed the decrease in per port price if increases in the backplane capacity of hubs could enable the deployment of higher speed standards.

These economic features raise two issues. One important issue regards the evaluation of the economic benefits that were being created as a consequence of technological improvements in hub equipment and in particular the extent to which economic benefits to hub users could be captured by a decline in the per port price of equipment.

Hub users who needed to link more end stations to their LANs were confronted with the following options. They could either attach new end stations to just one hub with port density high enough to support all of the additional end stations or, they could choose to distribute new end stations across more than one piece of hub equipment. In the absence of improvements in any of the technological characteristics of existing hubs but in a context where the price of hub equipment was declining, both possibilities could have entailed the same economic benefits in terms of price per port. However, the former option would have necessarily involved a higher deployment of end stations on just one segment and, therefore, a price per unit of bandwidth available to each port higher than in the case of the latter option.

Technological improvements both in the standard supported by the equipment and in their backplane technology could make a difference in the sense that the purchase of equipment supporting faster standards would have eased the problem of bandwidth allocation along one segment and produced an increase in the unit of bandwidth available to each port. The issue is to understand how consumers would value these technological improvements against the decline in the price of hub equipment which were not supporting these improvements.³

the output controllers. This connection occurs through a board which is called a 'backplane'.

³ It has to be noted that this is another version of the so called 're-packaging' problem (Trajtenberg, M. (1990), Greenstein, S. (1997)), which arises whenever a consumer is confronted with the choice between two alternative products one of which has undergone technological improvement in one technological characteristic and the other one has undergone a price cut. 'Repackaging' may occur any time consumers can benefit from an increase in product performance along a specific technological characteristic by purchasing more than one unit of a product not embodying technological improvements at a price which is lower than the price of the same product embodying the improved

In fact, if prices of hub equipment were declining overtime it might be possible for consumers to buy more than one low density hub supporting a slower standard rather than buying just one piece of equipment supporting both a faster standard and higher density and still be able to benefit from a lower price per unit of bandwidth per port. The same conclusion would apply if it were possible for consumers to buy equipment with a higher density, slower speed standard but an enhanced backplane. In both cases, per port price decline would not capture the extent of benefits to consumers from technological change.

However, the fact that hub equipment was being affected by technological change along more than one dimensions (i.e. both faster standards and backplane changes), further complicates the picture.

If technological improvements were occurring along several dimensions there was the definite possibility that users could assess the value of these improvements both against the benefit deriving from the purchase of cheaper, although not improved, equipment as in the former case, and against the benefit deriving from the purchase of equipment improved just along one dimension. In other words, we cannot rule out the possibility that, given the density of equipment, consumers might not be indifferent about the choice between purchase of a hub with a high speed standard and no improvement to the backplane and the purchase of a hub supporting a slow standard but with an enhanced backplane. As in the previous case, per port price decline would not capture the extent of benefits to consumers from technological change. Since the willingness to adopt new hub equipment depended on the evaluation of these improvements we should be able to envisage a methodology to measure them.

The other issue concerns the relationships between the timing of the unfolding of the trajectory of improvements and the creation of economic benefits for hub users. On the one hand, economic benefits to hub users could accrue more quickly, the higher high speed standards could ease the bottlenecks and the pace of increments to the backplane of hubs could enable the integration of high speed standards within existing LANs. On the other hand, the presence of obstacles to the removal of existing bottlenecks could prevent improvements from taking place. While in the former case the creation of economic benefits for hub users would proceed steadily and continuously, in the latter case there could be a slow down or even a discontinuity.

Technological improvements to hub equipment occurred along different dimensions and at different points in time over the period in question. It was a peculiarity of hubs, as opposed to other types of LAN equipment such as switches, to employ a shared system of data transmission. However, the way the system of data transmission was implemented in the backplane design of the equipment changed overtime. Almost all new equipment introduced at the beginning of the 1990s embodied a single segment shared backplane. Only a small proportion supported a multi-segment and/or a port switched shared backplane, although the number of manufacturers supplying both designs was increasing. The amount of new equipment embodying a multi-segment backplane peaked in 1993 and then decreased. By that time it had already become widespread practice among manufacturers to offer new equipment with port switched backplanes. The number of new pieces of equipment with a port switched backplane peaked in 1996 when multi-segment design was becoming less and less available in new equipment.

While both manufacturers and users were experimenting with new backplane designs new standards were endorsed and improvements along the two dimensions were combined in new equipment. Although its standardisation process had not yet been completed, few models of early hubs supporting FDDI with shared backplanes were already available to users in 1990. Both port switching and multi-segment backplane designs started to be developed from 1991 onwards as soon as the standardisation process was completed. In 1996 FDDI equipment with port-switched backplane was more popular than products with a multi-segment backplane design. In 1995, following its official standardisation which had occurred one year earlier, Fast Ethernet hubs with 'shared only' backplane designs became available to users. The development of both multi-segment and port-switched alternatives over Fast Ethernet followed.

It should be noted that, as already pointed out above, overlap between the chronology of new standards introduction and the development of new backplane designs resulted in a characteristic pattern of innovation. Early equipment supporting a new standard was usually implemented in equipment with a 'shared only' backplane design. Equipment with a new backplane design usually became available some time after the introduction of new standards. The sequence of changes in the backplane usually entailed implementation of a multi-segment design first followed by a port-switched design. The pace of innovation accelerated towards the end of the period when, as a result of the decision of most manufacturers to back port switching rather than to the multi-segment design, fewer and fewer products supporting new standards were available with a multi-segment

backplane. As a consequence, the pace at which Fast Ethernet equipment became available was faster than the pace of which FDDI equipment had become available at the beginning of the 1990s.

This brief history suggests that many events took place in the market for hubs from 1990 to 1999. The decline in the price of per port connection is just one among the events that enabled users to connect new end stations to existing LANs. During this period, users also witnessed an extension of hub capabilities. The development of new backplane designs and the introduction of new standards represented improvements that both extended the capabilities of the equipment and increased the benefits to users from the purchase of hubs. As a consequence, the willingness to deploy hubs became increasingly associated with these improvements. To develop a methodology to account for these improvements, therefore, is necessary in order to be eventually able to investigate the extent of the adoption of improved equipment.

Section 2: Representing technological change in hub equipment: The Constant-Quality Price Index Approach

The analysis in the previous section has highlighted that technological improvements in hub equipment occurred very rapidly, affected more than one technological dimension, and resulted in a decline in the price per connection. The aim of this section is to introduce and discuss the methodology that will be applied to address the issue of measurement of the extent of technological change in hub equipment. The methodology we will employ is the constant-quality price index approach, modified to account for the peculiarities of the process of technological change in the hub equipment case.

The constant-quality price index approach used in this paper is based on the application of the hedonic price technique to the estimation of product prices. Hedonic price is a well known technique for measuring product quality change following technological improvements. The hedonic approach was originally conceived to capture the utility to consumers from the purchase of a product conceptualised as bundles of ‘objectively measured characteristics’. It is assumed that it is possible to define for each consumer an indifference curve associating the amount of each one of the characteristic contained in each product to money for a given level of income and utility for the consumer. The marginal valuation placed by a consumer on a specific characteristic, for a given level on income and utility, is given by a point on the indifference curve and by movements along the curve following, in case changes in the amount of the characteristic contained in the product occur. The tangency between the indifference curve, the ‘indifference surface’ since each product embodies usually more than one characteristic, and the production indifference curve (surface)

determines the minimum price the consumer is willing to pay in the market price for a specific characteristic (bundle of characteristics). The rationale behind the hedonic price approach applied to the case of technological change is that we should be able to measure the marginal value attributed by the consumer to a change in the characteristics by assuming that the tangency between the two indifference surfaces is maintained or that the tangency point is affected but market equilibrium is immediately re-established (Rosen 1974).

The application of the hedonic technique to the empirical investigation of technological change, starts from the assumption that observed price differences across products are mainly due to quality differences which can be measured in terms of characteristics that are common to different models. With each characteristic a price can be associated which is not observable but can be derived from estimates of the coefficients of the characteristics obtainable by regressing the observed price of the product on its characteristics as shown in (1) below.

$$(1) \quad \ln P_i = a + \sum_k b_k \ln(z_{ki}) + u_i$$

where

P_i = price of the i th equipment

z_k = quantity of the k th characteristic in the i th equipment

a = intercept

u_i = error associated with the i th equipment

The derivation of both the price of the characteristics and of the price of the product from the coefficients of the characteristics depends on the functional form of the estimated equation.

Depending on the functional form chosen, the estimated coefficients of the characteristics can be also interpreted in different ways (as elasticity coefficients (double log form as in equation (1) above), rate of change of the price of characteristic (semi log form) etc.).

Hedonic estimations can be employed both to estimate the price of product characteristics at a given point in time, by performing individual regressions of observed prices on existing characteristics, and to estimate the coefficients of characteristics by making the assumption that coefficients can remain constant over time (annual vs. pooled regressions). It should be noted that it is not the possibility that changes may occur in product characteristics that makes one technique more suitable than another for the purpose of price estimation. The hedonic technique is suitable to deal with changes in product characteristics. Changes in characteristics usually entail reduction in the quality adjusted prices of improved products over time.

The suitability of either annual or pooled regression depends on the assumptions made about the relationships between changes in the characteristics and prices of products within any time period. As we have pointed out above, a crucial theoretical assumption underlying the hedonic approach is that equilibrium between demand and supply is assumed to exist. This may occur either if all products sold in the same time period embody the same technology or if products embody different technologies but prices of products embodying old technologies adjust instantaneously to the price of those embodying new technologies.

These are the assumptions that underlie estimations that employ a ‘pooled years’ approach. In cross section estimations, ‘pooling’ refers to the grouping of equations pertaining to different years according to certain specified criteria. The grouping is made by introducing in the regression time dummy variables. The use of a time dummy variable (D_t) allows the different models that satisfy the criteria to be identified by assigning to them the same coefficient (d_t) while the relationship between price and the characteristics is estimated as shown in equation (2) below which is an extended version of (1).⁴

$$(2) \quad \ln P_{it} = a + \sum_{t=1} d_t D_t + \sum_k b_k \ln(z_{ki}) + u_i$$

Time dummies may reflect the introduction of a specific new technology and/or a new generation of products. In this case, for all the products embodying a specific technology, and/or belonging to the new generation, the coefficients can be assumed to remain constant over the entire time period specified by the time dummy. Therefore, pooling may be used to reflect the shift in the hedonic surface associated with the introduction of a new technology at a specific point in time.

This approach was first applied by Chow (Chow 1967) and subsequently by Stoneman (Stoneman 1976) to the construction of constant-quality price index for computers. Their findings supported the existence of a decreasing index for computers in the time period their research covered, as represented by a negative and increasing, in absolute value, coefficient for the time dummy variable.

Pooling year regressions are particularly suitable in those cases where there is a clear cut distinction between those products embodying a new technology and those embodying an old one in each year

⁴ To avoid exact collinearity with the intercept, a time dummy for one year (the reference year), is omitted. The intercept represents the estimate of the omitted year dummy. Usually the omitted year is the first year of the sample so that, by making a comparison with it, the shift in price in the following years can be assessed.

and/or in those cases where it is possible to clearly assign the same price to old and new technology embodied new products. This approach may seem to be less suitable when, as in the case of hub equipment, there are plausible reasons to assume that products embodying different technologies are sold in the same time period and when products embodying old and new technologies are sold at different prices in the same time period.

When product models embodying new technologies are introduced and sold in the market alongside new models that do not embody technological change, it may be that the models embodying technological improvements are sold at a lower price than new models embodying old technologies. The situation where different sets of prices for a product with the same characteristics may coexist at a point in time may be interpreted as a situation of disequilibrium.

Disequilibrium would last longer when technological change affects different characteristics at different points in time as we have seen in the previous section in the case of hub equipment. On the one hand, the higher the extent of technological change in products characteristics, or the higher the number of characteristics that undergo improvements at the same point in time, the higher may be the extent of disequilibrium in market prices for hub equipment. On the other hand, if improvements occur at different points in time, the number of product characteristics affected by technological change is higher and the more likely it is that improvements may occur in sequence and before prices have adjusted to a new equilibrium.

As pointed out by Dulberger (Dulberger 1989) this state of ‘technologically induced’ market disequilibrium, which may cause existing products to be ‘leapfrogged’ by new products, has to be taken into consideration when estimating the hedonic regression. Since the forces causing disequilibrium are likely to be correlated with product characteristics, overlooking them may lead to a biased estimation of the coefficient of the characteristics. The solution Dulberger proposed for the estimation of coefficients in this case, was the introduction of ‘technology class’ dummies alongside time dummies.

As highlighted above, technology class dummies aim at capturing those cases where new products do not embody the same levels of technology. They will be present for those new products whose characteristics assign them to a specific technology class in each given year. Moreover, technology class dummies aim at capturing those cases of products that may embody different technologies and do not compete at the same quality adjusted price within a given year. In these instances the

coefficient of the technology class will be statistically different from zero. After defining m technology classes on the basis of the technology embodied by each product, technology class dummies (T_m) may be incorporated into (2) as follows.

$$(3) \quad \ln P_{it} = a + \sum_{t-1} d_t D_t + \sum_{m-1} c_m T_m D_t + \sum_k b_k \ln(z_{ki}) + u_i$$

The above equation will be used for the empirical estimation.

Section 2.1: Defining technology classes in the case of hub equipment

The construction of technology classes for the hedonic estimation requires the definition of some criteria which can be used to construct dummy variables. As we have seen above, technology classes should be defined on the basis of changes in technological dimensions which are representative of the performance of the product. Dulberger, for instance, in her investigation of computer processors (Dulberger 1989), decided that a processor could be assigned to a technology class whenever a change occurred either in the memory material, density or type of the processor.

In the case of hub equipment, the issue of identification of the technological dimensions used to define the technology classes requires identification of those dimensions along which technological change occurred over the 1990s. As can be seen from the section above, on the one hand, it would be fairly straightforward to define a technology class only on the basis of the ‘type’ of standard supported by the equipment, since standards define the rules and the speed at which data transmission occurs. On the other hand, we have argued that in the case of hub equipment, improvements in capacity of data transmission, following from the endorsement of new standards with higher bandwidth, required additional changes in equipment backplane design in order to be effectively implemented. This aspect must not be overlooked when it comes to defining technology classes. A definition of technology classes for hubs constructed along these two dimensions is summarised up in Table 1 below.

Table 1
Hub Technology Classes 1990-1999

Class Code	Backplane Type	Standard	Years in sample	Years ‘best’
TC1	Port Reconfig	Ethernet	1990-1997	1990, 1992
TC2	Shared only	Ethernet	1990-1999	
TC3	Multi-Segment	Ethernet	1990-1998	
TC4	Port Reconfig	FDDI	1991, 1993-1997	1991, 1993-1995
TC5	Shared only	FDDI	1990-1997	
TC6	Multi-Segment	FDDI	1990-1997	
TC7	Port Reconfig	Fast Ethernet	1996-1998	1996-1998
TC8	Shared only	Fast Ethernet	1995-1999	1999
TC9	Multi-Segment	Fast Ethernet	1996-1998	

As the table shows, three backplane types and three standards supported by hub equipment have been chosen to define the technology classes, which are nine in total. Not all the technology classes are present in the sample in each year. Only hubs belonging to TC2 (Ethernet shared only) are present in each year of the sample. Hubs supporting FDDI are present in the sample until 1997, while hubs supporting Fast Ethernet are present from 1995 first implementing a ‘shared only’ backplane and then implementing also other backplane types. The last column of the table shows the years in which each technology class may be considered to have been the ‘best’ available. A few words are needed regarding the possibility of comparing technology classes so that a ‘best’ technology class can be defined for each year of the sample.

There are two issues to be considered when an attempt is made to rank hub equipment according to its performance. The first issue concerns the possibility to unequivocally assess equipment performance since trade off exist between some of the technological characteristics of the equipment which should be considered when assessing equipment performance. Contrary to many other LAN equipment (i.e. router and switches), hub equipment is not technologically complex and its performance can be assessed along a relative low number of technological characteristics. The second issue arises when we consider that the performance of hubs, as with the performance of any other LAN equipment, depends on the architecture of the LAN in which they are deployed because LAN architecture defines the interaction between the components of the system. Although it is possible to distinguish certain types of LAN architectures which stress the performance of some equipment rather than others, the extent of idiosyncrasy of each LAN is very high and it would be impossible to capture each possible case or even reduce them to a few that could be clearly identifiable for measurement purposes.

An attempt to partly reduce this idiosyncrasy may be made by relying on some features of the equipment which can be considered to be proxies for the LAN architecture in which the equipment can be deployed. Port density is one of those characteristics.⁵ For a given standard and backplane type, port density gives an idea of the maximum amount of bandwidth that can be allocated to each end station when it wants to transmit. Therefore, port density is a measure of the capacity of the equipment to support a certain number of end stations and it is an indirect indication of the type of LAN in which the equipment could be deployed. We have decided to define as ‘best’ those

⁵ There are also other characteristics that can be considered to represent a good proxy for equipment density and therefore for LAN architecture. Equipment configuration is one of these characteristics. These characteristics do influence the price of the equipment. Rather than using them in the definition of technology classes, we will include these variables as dummy in the regression.

combinations of backplane and standard which might provide the highest amount of bandwidth per end station for a given port density of equipment.

This assumption is particularly helpful for two reasons. First, by making this assumption we can rank backplane types from shared only to port reconfiguration hubs in ascending order of performance. Second, this assumption rules out the possibility that a port reconfiguration Ethernet hub could be thought to perform as well as or better than a FDDI, a Fast Ethernet Shared Only and/or Multi-segment equipment. A further problem would be represented by the impossibility to unequivocally define which piece of equipment is better between one supporting Fast Ethernet and another supporting FDDI, both with a port reconfiguration backplane. However, this problem does not arise in our case since these two technology classes are never present in the same year in the sample.

Section 3: The Data

This paper employs data on hub equipment prices and technological characteristics collected from several sources. The data in this paper begin with the 10Base-T Hub equipment Buyer's Guide published in the 8 October 1990 issue of *Network World* and end with the Low-end Hub equipment Buyers' Guide published in the 1 April 1996 issue. After this issue, *Network World* ceased publication of the Buyers' Guide for hub equipment. The value of *Network World* as a source of information relies upon its being the publication targeted to network professionals who need detailed and up-to-date information on both product characteristics and market strategies of manufacturers. The drawback of this source is that, focussing on the latest new features added to existing products, although useful to capture a specific trend in the market, may lead to those products that, although not new, embody some characteristics that may be useful to capture the *general trend* of the market being overlooked. This is evident in the tendency of the Buyer's Guide, especially in the most recent years, to focus on specific market segments within the hub equipment market (i.e. Fast Ethernet and/or 'chassis based' Hubs only), instead of focussing on the whole market for equipment.

To overcome both this problem and the risk of providing a partial picture of the 'state of the market', we have considered other sources of information that could integrate the main one especially for the years after 1996. For 1997 and 1998 and 1999 information has been collected from Product Reports by *Data Pro-Information Services* a consultancy company, and from the Buyer's Guide published by *Data Communications* another trade journal respectively.

Finally, available information for each year has been integrated with additional information taken from product data sheets. The decision to use other sources than *Network World Buyer's Guide* to integrate the available information have introduced a trade off in the data set construction. On the one hand, more information on product characteristics could be retrieved, especially from product data sheets, and this information could be used for integration purposes. On the other hand, this information was generally not available with enough references to the date of first market introduction. These details were essential to enter products in the data-set.

Section 3.1: Description of the Sample

The sample considers *only new hub equipment* introduced in the market in each year of the 1990-1999 time period. Generally, the date of product introduction coincides with the presentation of the equipment at trade fairs and industry meetings such as NetWorld, Interop and ComNet, which are held at least twice a year. Trade journals, and in particular *Network World*, give extensive coverage of these events and report in detail the characteristics of new products announced there. This facilitated the task of tracing the dates of market introduction for some of the products included in the sample. For the early years of the sample, dates of market introduction have been double checked against information reported by the trade journal *Microcomputer Industry Update*.⁶ Since this journal ceased publication in 1995, dates of market introduction from 1995 onward have been double checked with press communications and product announcements released by equipment suppliers and obtained from company' web sites. Table 2 presents a summary of the sample data.

Table 2
Hub equipment Product Sample Data

Year	Models with Characteristics Data	No of Firms
1990	42	23
1991	44	28
1992	94	54
1993	77	43
1994	67	24
1995	80	39
1996	81	38
1997	29	21
1998	17	7
1999	5	3
TOT	536	=

⁶ Microcomputer Industry Update is a publication containing a digest of articles from several trade journals such as: Byte, ComputerWorld, PC Magazine, PC World, Computer Reseller News, InfoWorld, PC Week, Systems and Network Integration.

Section 3.2: Equipment Price and Characteristics

In this paper the technological characteristics of hub equipment that have been chosen for constant-quality price index construction are Backplane Capacity and Maximum Port Density. Backplane capacity is one of the most important characteristic because it allows the performance of the central core of the equipment to be assessed. A measure of equipment performance is represented by the capacity of the backplane to support internal data transmission (internal transmission capacity or ITC). In the case of hub or LAN equipment implementing a shared backplane, ITC coincides with the MAX physical bandwidth (in Mbps) which varies according to both the standard and the backplane design of the equipment. The Maximum Port Density supported by each piece of equipment is a measure of the capability of the equipment to link together a certain number of end stations. Equipment supporting a high number of end stations is generally more expensive than that supporting only a few end stations. However, as argued above, there is no clear link between port density of the equipment and the extent of economic benefits to users.

Table 1 in the Appendix shows the pattern of changes in the two characteristics for typical hub equipment present in the sample. Peaks in the increasing pattern of the average backplane capacity reflect the occurrence at different points in time of modifications in backplane design to accommodate new standards (1991), of the introduction of new standards (1995), or of both (1997). Increases in the maximum port density follow a more regular pattern than increases in the average backplane capacity. The decrease in the value of port density in 1995 can be attributed to the low number of modular products present in the sample in that year when compared both to previous and following years. Modular products usually have both higher port density and higher backplane capacity than fixed configuration products. Therefore, the presence of these product types can positively affect the average values of both characteristics. It is significant that after 1997, when only fixed configuration equipment is present in the sample, the average value of both characteristics experiences a big slump. At the end of the time period covered by the sample, while the average value for backplane capacity is still higher than it was at the beginning of the time period, the average value of port density is lower confirming that the absence of modular products in the sample has a negative influence on this characteristic.

The effect of equipment configuration on the mean values for both characteristics is confirmed when we look at the sample statistics broken down by product configuration. Tables 2 and Table 3 in the Appendix report the same statistics for each of the characteristics as displayed in Table 1 broken down according to equipment configuration (fixed and modular respectively). Two things should be noted. First, the mean values for each characteristic is higher in the case of modular than

in the case of fixed configuration products. Second, the pattern of increase in the value of product characteristics is more regular in the case of modular than in the case of fixed configuration equipment.

The most important price issue again concerns the configuration of equipment. Depending on equipment configurations different types of information on equipment prices can be retrieved. Such heterogeneity of information can create problems and solving these problems involves making some choices on which 'types' of prices have to be included in the sample. Depending on equipment configuration, the following information on prices can be available. Price of the standalone product in the case of fixed configuration equipment. Price of the chassis and/or price of the individual module in the case of modular configurations. Fixed configuration equipment is the most straightforward because only one price applies. Modular equipment is more problematic because it can support more than one technology and offer different combinations of port density according to how the modules are mixed and matched. In those cases where separate information on both chassis and module prices is available different prices corresponding to different equipment configurations can be calculated. In this paper we present the following three types of prices: the prices of minimum and maximum configurations and the price of average configuration. Maximum configuration price is the price of hub equipment fully equipped with modules implementing the fastest standard at the highest density available. Minimum configuration price is the price of equipment fully equipped with modules implementing the lowest standard at the highest density available. Mean configuration price is the arithmetic average of the two prices.

Section 4: Empirical results

By using the equations introduced in Section 2, we have estimated three alternative model specifications. The first model (Model A in Table 3 below) corresponds to equation (2). It is the traditional hedonic equation including equipment price as a function of the relevant chosen characteristics, backplane capacity and maximum number of ports supported, two dummy variables to account for other standards that may be supported by the equipment but that have not been included in the definition of the technology class (TR dummy and Other Tech Dummy respectively), a dummy variable to account for whether the equipment implements some kind of management of the data flows and transmission (Management Dummy) and time dummy variables. As can be seen, both characteristic variables contribute directly, and approximately in the same way, to the determination of the price of hub equipment confirming that both characteristics fulfil important functions. As for the technology dummy variables, it can be seen that the two variables

have opposite signs. While the TR Dummy has a positive influence on the equipment price, the other dummy has a negative influence. One of the possible reason for this difference of sign is that Other Tech Dummy is constructed from a combination of different standards that are present in the sample only for some years, while TR Dummy captures the influence of just one standard (Token Ring) that is present all but the last two years. Finally, the contribution of the management dummy to the determination of the price of the equipment is very high. One of the possible reason why the coefficient for this variable is so high is that, since management is sometimes implemented through an additional module, the coefficient of this variable also captures the positive relationship between type of configuration and equipment price. All the coefficients of the variables are significant at 5% confidence interval. A complete list of the coefficients and relevant statistics, including those of the time dummy variables, is given in Table 4 in the Appendix.

Table 3
Regression Summary: 1990-1999 pooled regressions

Characteristics	Summary					
	Model A		Model B		Model B'	
	Coeff	t	Coeff	t	Coeff	t
Back plane Capacity	0,434	14,4	0,363	8,8	0,362	11,2
Max No of Ports	0,489	10,6	0,510	10,1	0,517	11,5
TR Dummy	0,289	2,6	0,329	2,7	0,312	2,9
Management Dummy	0,638	4,9	0,680	5,2	0,592	4,7
Other Tech Dummy	-0,578	-3,5	-0,530	-2,7	-0,394	-2,4
Intercept	5,281	26,9	4,952	14,2	5,448	28,2
Year dummies		*		*		*
Technology class by year				*		*
RSQ	0,703		0,753		0,723	
MSE	0,926		0,847		0,869	
Sample size	530		530		530	

Dependent (Price of max configuration) and independent variables in natural logarithms.

* indicates that dummies are present in the regression

Model B is an implementation of equation (3) where equipment price is a function of technological characteristics and other dummy variables, time dummy variables and technology class by year dummy variables. The introduction of technology class by year dummy variables has been carried out according to the following rules as suggested by Dulberger (Dulberger 1989). Technology class by year dummy variables has been introduced for each but one technology class and for each but one year in the sample. The omitted year was 1990 and the omitted technology class for each year was that defined as 'best' according to the criteria discussed above. The 'start' year was chosen to be 1990 because, in this year, the so called 'second generation LANs' period started with the introduction in the market of equipment supporting FDDI and port reconfiguration backplanes

(Minoli 1993). The estimated coefficients of the technology class by year dummy variables for each year represent price differences in log form between each of the technology classes existing in a specific year and the ‘best’ technology class in 1990. Moreover, the combination of the omitted 1990 time dummy variable and the omitted best technology class for each year results in an estimated coefficient for the time dummy variable in each year that represents the price difference between the ‘best’ technology in that year when compared with the ‘best’ in 1990. The coefficients representing technology class and time differences and their t values from the estimation of model B are displayed in Table 4 below, while the complete list of the coefficients and relevant statistics is reported in Table 5 in the Appendix.

Table 4

Coefficients from regression of price on characteristics and technology class by year dummies

Year	Technology Class									
	Best	1	2	3	4	5	6	7	8	9
1990		*	0,670 (1,9)	**		-0,545 (-0,8)	1,410 (1,3)			
1991	0,048 (0,1)	-0,674 (-0,7)	-0,424 (-1,4)	0,591 (-1,4)	*	1,544 (4,9)	-1,122 (-1,6)			
1992	-0,166 (-0,4)	*	-0,447 (-1,6)	-0,082 (-0,2)		0,741 (2,7)	0,391 (0,5)			
1993	-0,217 (-0,5)	0,117 (0,4)	-0,242 (-0,9)	0,006 (0,0)	*	0,813 (2,5)	-0,420 (-0,9)			
1994	-0,309 (-0,8)	0,235 (0,6)	-0,003 (0,0)	0,188 (0,5)	*	0,844 (2,3)	-0,899 (-1,7)			
1995	-0,713 (-2,0)	-0,028 (0,0)	0,386 (1,6)	0,079 (0,2)	*	**	0,092 (0,1)		0,610 (1,5)	
1996	-0,279 (-0,8)	0,262 (0,7)	-0,242 (-0,9)	0,435 (1,4)	-0,615 (-1,2)	0,703 (1,4)	-0,715 (-1,3)	*	-0,314 (-1,2)	0,434 (0,8)
1997	-0,364 (-0,5)	1,067 (1,5)	-0,133 (-0,2)	-1,137 (-0,8)	**	1,269 (0,9)	**	*	-0,555 (0,9)	-0,423 (0,9)
1998	-1,806 (-2,3)		0,549 (1,1)	-2,098 (-1,7)				*	0,071 (0,1)	1,821 (1,8)
1999	0,180 (0,2)		-1,600 (-1,5)						*	

*Identifies the best technology class

**Technology Class present in the sample but omitted to avoid collinearity

t values in brackets significant in bold

A comparison between model A and model B highlights how the addition of technology class by time dummy variables has the effect of improving the model fit by both increasing the R^2 , as expected, and of decreasing the mean square error of the regression. This improvement is confirmed by the results of the F test (see Appendix). Moreover, it can be seen that in only a few cases, highlighted in bold, are estimated coefficients not significantly different from the coefficients of the best technology class (zero) within the same year.

A 'restricted' specification of Model B which takes into account only those technology classes whose coefficients are statistically different from zero and which assigns a value of zero to the coefficients not statistically different from zero is estimated as Model B'. Table 5 displays the coefficients representing technology class and time differences and their t values from the estimation of model B'. Again the complete list of the coefficients and relevant statistics is reported in Table 6 in the Appendix.

Table 5
Coefficients from regression of price on characteristics and technology class by year dummies

Year	'Best'	Technology Class								
		1	2	3	4	5	6	7	8	9
1990		*	0	0		0	0			
1991	-0,779 (-3,2)	0	0	0	*	1,342 (4,5)	0			
1992	-1,011 -5,6	*	0	0		0,935 (3,7)	0			
1993	-0,837 -4,2	0	0	0	*	0,587 (2,4)	0			
1994	-0,737 (-3,7)	0	0	0	*	0,433 (1,5)	0			
1995	-0,794 (-4,4)	0	0	0	*	0	0		0	
1996	-0,815 (-4,4)	0	0	0	0	0	0	*	0	0
1997	-0,881 (-3,5)	0	0	0	0	0	0	*	0	0
1998	-1,831 (-6,6)		0	0				*	0	0
1999	-1,542 (-3,5)		0						*	

*Identifies the best technology class
t values in brackets

A comparison between Model B' and Model A highlights that, although restricted to those classes with coefficients statistically different from zero, the introduction of technology classes improves the goodness of fit of the regression with respect to the case when only time dummy variables are considered. A comparison between Model B and Model B' highlights the fact that, as expected, Model B' has both a higher MSE and a lower R^2 than Model B. A comparison between Model B and Model B' should be made to ascertain whether we can use the estimated values from Model B' to construct price indexes for each technology class. A test to ascertain whether Model B and Model B' are statistically different from each other is the F test. From an F test comparing Model B and Model B' we obtain a value of 1,323 with a critical value equal to 0,90 at 5% level which enables us to reject the null hypothesis that the two specifications are different.

Once it is established that Model B and Model B' are not statistically different from each other, we can use the estimated coefficients for time dummy and technology class dummy variables from Model B' to derive price indexes for each technology class. The choice of 1990 as the reference year and Technology Class 1 as the 'best' in 1990 implies that the values of the price of the technology classes are relative to this class and to this year. Price indexes for each technology class in each year are shown in Table 6 where, to allow for a comparison, the value of Technology Class 1 in year 1990 is set equal to 100.

Table 6
Price Indexes by technology class (1990 'best' = 100)

Year	'Best'	Technology Class								
		1	2	3	4	5	6	7	8	9
1990	100,0	100,0	100,0	100,0		100,0	100,0			
1991	45,9		45,9	45,9	45,9	175,7	45,9			
1992	36,4	36,4	36,4	36,4		92,7	36,4			
1993	43,3	43,3	43,3	43,3	43,3	77,9	43,3			
1994	47,9	47,9	47,9	47,9	47,9	73,8	47,9			
1995	45,2	45,2	45,2	45,2	45,2	45,2	45,2		45,2	
1996	44,3	44,3	44,3	44,3	44,3	44,3	44,3	44,3	44,3	44,3
1997	41,4	41,4	41,4	41,4	41,4	41,4	41,4	41,4	41,4	41,4
1998	16,0		16,0	16,0				16,0	16,0	16,0
1999	21,4		21,4						21,4	

Best technology class in bold

Analysis of Table 6 reveals that quality adjusted prices for the best technology decrease evenly for each of the years in the sample except for 1993 and 1999. While in the former case the increase can be attributed to a switch in the best technology from Ethernet to FDDI, in the latter it may be related to a sample phenomenon given that few observations are available for 1999. A multiple price regime is found in four years (1991, 1992, 1993, 1994). This is evidence both of market disequilibrium and of the fact that the adjustment process was not instantaneous. As expected, in those years in which disequilibrium occurred, equipment belonging to the best technology class is priced lower than that belonging to other technology classes.

Looking at the results from the viewpoint of the standard supported by equipment, an inter-standard multiple price regime is found only when FDDI is the best technology (TC4, TC5 and TC6), while a single price regime occurs when either Ethernet (TC1, TC2 and TC3) or Fast Ethernet (TC7, TC8 and TC9) are the best technologies. The latter case depicts a situation of 'inter standard equilibrium' in which if disequilibrium actually followed from the improvements that took place, adjustment to a new equilibrium occurred instantaneously. In the FDDI case, it took four years for the market to adjust to a new equilibrium after technologically induced disequilibrium occurred. During this

period products belonging to different technological classes within the same standard coexisted in the market at different price levels.

The presence of technological induced disequilibrium is the main difference between the first and the second half of the decade. Quality adjusted prices for the second half of the decade display a rather different pattern. The second half of the decade shows a situation of equilibrium in the market for hub equipment. Moreover, equipment prices adjusted for quality continue to decrease steadily and at an even pace for each of the technology classes until 1998 when the number of technology classes is reduced first to five and then to just two for the final year of our sample. This pattern is rather surprising especially considering that a new standard, Fast Ethernet, was introduced in 1995 and that therefore we would expect to experience a pattern similar to that for first decade. Three possible explanations of these results can be advanced.

First, there is the possibility that technological improvements in standards are generally technologically less disruptive than backplane changes and, therefore, affect equipment prices less than changes in backplane. This interpretation seems plausible to the extent to what, as we have already stressed, both backplane changes were necessary to implement new standards and they usually followed their official endorsement. However, this interpretation would not be suitable to explain those cases in which differences in the extent of both price disequilibrium and adjustment period arise between different standards.

Second, there is the possibility that the extent of the improvement is not determined by the change in a specific characteristics type but is rather the extent of the change that determines the extent of the disequilibrium. According to this hypothesis, which is an extension of the previous one, the introduction of a standard such as Fast Ethernet impacted on the extent of disequilibrium less than the introduction of FDDI did in the first half of the decade because the introduction of Fast Ethernet entailed fewer changes in equipment than FDDI. Similarly, both Ethernet and FDDI when they were introduced as 'best technology' in 1992 and 1991, and 1993 respectively, gave rise to multiple price regimes but, while no adjustment was instantaneous for Ethernet, disequilibrium lasted for FDDI. If disequilibrium lasted, it means that consumers were more willing to tolerate it, or suppliers more were less capable of offering old equipment at competitive prices. While this latter interpretation might capture a piece of the actual story about the extent to which competition in the FDDI equipment market has never been as fierce as in market for Ethernet and Fast Ethernet, it is also true that price indexes offer evidence that decline in the price of FDDI products has occurred at

least at the same rate as for other standards. Why then were consumers more willing to tolerate a multiple price regime in the case of FDDI than in the case of Ethernet in the first half of the decade and/or Fast Ethernet in the second half of the decade?

As stressed in the literature, (Fisher, McGowan *et al.* 1983; Dulberger 1989) (Berndt and Griliches 1993; Oliner 1993), price differences between equipment embodying the new or best technology and equipment embodying 'old' technology can reflect a sort of 'risk premium' that consumers would be willing to pay for old products because these products embody characteristics that are better known to them than new ones. This would explain why the introduction of port reconfiguration FDDI as the best technology class in 1991 induced disequilibrium in the 'FDDI shared-only' technology class (the eldest) rather than in the still not completely known, multi-segment one. Consumers who were looking for higher speed and better performing equipment were exploring new opportunities that equipment implementing a combination of new standards and backplane designs represented. To explore these new opportunities they started from a technology class which, although it was a new combination, might not represent the frontier and therefore it might entail a price differential with respect to the best technology class available.

The same explanation would apply to the case of Fast Ethernet. Contrary to the case of FDDI in the first half of the decade, disequilibrium following the introduction of the new standard did not occur in the market because, given the technical similarities between Fast Ethernet and Ethernet, which was the standard most widely implemented in existing LANs at that time, and given the fact that all the three alternative backplane designs had already been in circulation for many years, the 'risk premium' was reflected by an increase in the price of equipment embodying old technologies.

Finally there is a third explanation that would be suitable to account for the reduction in the number of technological classes combined with a situation of equilibrium in the market. The presence of market equilibrium despite a new standard having been introduced at the beginning of the sub-period can be a symptom of the exhaustion of the technological trajectory characterising the rate and direction of technological improvements until that point in time. By the end of the decade technical solutions combining high speed standards upgrades in backplane design to provide an increase in bandwidth were no longer popular among suppliers who, at that time, were concentrating all their efforts and resources on the development of switch equipment. Switches, better performing and technologically sophisticated equipment than existing hubs, were therefore the outcome of a technological trajectory which had experienced a progressive unfolding in the

sequence of incremental changes in hub backplanes and whose development had been pursued intensively from the middle of the decade as economic resources began to be progressively displaced from the development of hub equipment towards the achievement of improvements in switches. This pattern is reflected in the decline in the amount of new hub equipment introduced in the market starting from 1997 and in the reduction in the number of technology classes available in 1998 and 1999. Most notably, the technological classes that disappeared were those which had constituted the technological frontier up until that point in time. For each standard, only those equipment implementing a shared only backplane (i.e. that belonging to the eldest technology class), continued to be introduced until the end of the decade. Although by that time hub equipment had been leapfrogged by switches, it was still competing in the market as low end, technologically unsophisticated equipment and this is reflected in the decreasing pattern of quality adjusted price.

Section 5: Conclusions

This paper is a first attempt toward disentangling the relationship between technological improvements in product characteristics and the extent of the creation of economic benefits in the case of hub equipment for Local Area Networks. The thesis of the paper is that technological change that has created economic benefits for users of hub equipment in the 1990-1999 decade has been associated both with improvements along several characteristics and with an extension in some of the capabilities of the equipment. This paper intends to capture the extent of technological improvements through the construction of a constant-quality price index for hub equipment. A summary of the analysis carried out in the paper is provided by answering the questions that have been put forward in the introduction.

Has the rate of growth of economic benefits occurred evenly over time? By using a constant-quality price index as methodology this paper has argued that there has generally been an even decrease in the quality adjusted price of hub equipment over the 1990-1999 time period suggesting that, the extent of economic benefits, as measured by the decline in the quality adjusted price index of hub equipment, should have been evenly distributed over time, the first and the second half of the decade have been characterised by rather distinct patterns of prices. Technologically induced disequilibrium has characterised the first half of the decade. While equilibrium has prevailed in the second half.

Have these economic benefits from technological improvements been evenly distributed across each characteristic? The empirical results have shown, that both the extent of technological

improvements, as measured by the decrease in the constant-quality price index, and the extent of economic benefits from technological improvements, of which the extent of market disequilibrium represents a proxy, have been unevenly distributed across existing technology classes. Moreover, the number of technology classes have been changing overtime, first increasing, with the introduction of new standards, and then decreasing toward the end of the time period suggesting that the focus of technological change has economic benefits creation has shifted over time.

What is the extent of the economic benefits from technological improvement that can be captured by using constant-quality price indexes? The paper has argued that through the inspection of the time pattern of quality adjusted price indexes constructed by applying an existing modified version of hedonic price estimation we may capture the extent of technological improvements and gain an understanding of the extent of the economic benefits. However, in the paper we have also argued that the chosen methodology may not be the most suitable one to capture those benefits arising from an extension in product capabilities which might not reflect in the decline of equipment price or to capture economic benefits when, as the empirical analysis has shown, technological improvements occur along many dimensions at the same time and users have the possibility to choose from products embodying old technologies and products embodying new technologies coexisting in the market with different prices. It is the purpose of future research to devise a more suitable methodology to address this problem in order to measure these benefits.

In sum, the relationships between the extent of technological change and the creation of economic benefits to users can be complicate and difficult to disentangle. There are many implications of this conclusion both for the conceptualisation and for empirical studies of the process of diffusion of new products. The main concern of this paper has been to show that there are some applications of the constant-quality adjusted price approach that can be used to explore the relationships between both timing and extent of technological improvements and the extent of creation of economic benefits. These applications should be taken in to account when analysing the determinants of new products diffusion in those industries in which technological change may affect existing products very rapidly, at an uneven pace and along several technological characteristics.

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APPENDIX

Table1
Sample Statistics (All Hub Equipment)

Year	Sample Size	Minimum	Maximum	Mean	Std. Deviation	Variance
Backplane Capacity (Mbps)						
1990	42	10,0000	288,0000	47,5238	61,3281	3.761,1336
1991	44	0,0000	3.200,0000	282,8636	658,7806	433.991,8879
1992	94	10,0000	1.400,0000	94,4681	199,3023	39.721,4129
1993	77	0,0000	12.000,0000	754,0909	1.883,1813	3.546.371,6890
1994	67	10,0000	13.000,0000	893,0149	2.492,3516	6.211.816,6513
1995	80	10,0000	40.000,0000	1.050,7250	5.179,5374	26.827.607,8222
1996	81	10,0000	10.000,0000	918,0741	2.320,4666	5.384.565,3444
1997	29	10,0000	70.000,0000	5.661,7931	13.157,5812	173.121.943,2414
1998	17	10,0000	1.000,0000	164,1176	228,9394	52.413,2353
1999	5	100,0000	100,0000	100,0000	0,0000	0,0000
Maximum Port Density (No of Ports)						
1990	42	4,0000	144,0000	39,4286	42,5166	1.807,6655
1991	44	8,0000	336,0000	54,1364	65,5657	4.298,8647
1992	94	4,0000	576,0000	68,9681	99,9408	9.988,1603
1993	77	8,0000	672,0000	114,9481	132,0302	17.431,9710
1994	67	6,0000	504,0000	109,0597	131,9690	17.415,8146
1995	80	6,0000	768,0000	76,9750	135,2430	18.290,6576
1996	81	4,0000	576,0000	100,3210	147,7389	21.826,7957
1997	29	6,0000	504,0000	160,6552	169,9505	28.883,1626
1998	17	4,0000	26,0000	15,7647	7,3103	53,4412
1999	5	8,0000	25,0000	17,0000	7,4162	55,0000
Minimum Configuration Equipment Price (thousands of US \$)						
1990	42	0,0033	0,7133	0,0618	0,1246	1552,9019
1991	44	0,0034	0,4800	0,0732	0,0930	864,6360
1992	94	0,0001	0,9800	0,0490	0,1169	1366,4873
1993	77	0,0015	0,6625	0,0677	0,1134	1287,0569
1994	67	0,0030	0,8562	0,0738	0,1216	1478,7726
1995	80	0,0013	1,3744	0,0651	0,1844	3400,8766
1996	81	0,0020	6,0938	0,2992	0,8047	64753,1479
1997	29	0,0025	12,9718	0,9264	2,3989	575476,1209
1998	17	0,0008	0,1100	0,0182	0,0278	77,0838
1999	5	0,0050	0,0370	0,0134	0,0133	17,7479
Maximum Configuration Equipment Price (thousands of US \$)						
1990	42	0,0040	0,6900	0,1231	0,1545	2385,6214
1991	44	0,0050	0,8741	0,2352	0,2596	6738,8365
1992	94	0,0031	1,0320	0,1002	0,1585	2512,1016
1993	77	0,0043	7,1682	0,4760	1,1603	134630,6357
1994	67	0,0030	5,2517	0,4127	0,8268	68361,8322
1995	80	0,0013	5,9486	0,2433	0,7816	61087,1083
1996	81	0,0020	8,3105	0,4418	1,2773	163138,6134
1997	29	0,0050	9,5501	0,7158	1,7714	313792,8365
1998	17	0,0008	0,1100	0,0238	0,0278	77,3576
1999	5	0,0100	0,0370	0,0194	0,0105	11,0368
Average Configuration Equipment Price (thousands of US \$)						
1990	42	0,0040	0,5250	0,0925	0,1221	1490,7242
1991	44	0,0050	0,5250	0,1542	0,1622	2632,2874
1992	94	0,0016	0,5629	0,0746	0,1125	1266,3400
1993	77	0,0043	3,6693	0,2719	0,5989	35867,6153
1994	67	0,0030	2,8230	0,2433	0,4396	19324,1844
1995	80	0,0013	3,1714	0,1542	0,4347	18897,6703
1996	81	0,0020	5,1385	0,3705	0,8934	79814,6917
1997	29	0,0050	6,5443	0,8211	1,4970	224086,8710
1998	17	0,0008	0,1100	0,0210	0,0276	75,9435
1999	5	0,0075	0,0370	0,0164	0,0118	14,0272

Table 2
Sample Statistics (Only Fixed Configuration Hub Equipment)

Year	Sample Size	Minimum	Maximum	Mean	Std. Deviation	Variance
Backplane Capacity (Mbps)						
1990	39	10,0000	288,0000	39,1282	54,3997	2.959,3252
1991	33	0,0000	1.000,0000	102,4848	196,8464	38.748,5076
1992	85	10,0000	1.400,0000	88,4706	204,7667	41.929,3950
1993	55	0,0000	12.000,0000	374,3273	1.663,9370	2.768.686,3354
1994	50	10,0000	3.500,0000	190,5200	572,4800	327.733,3567
1995	72	10,0000	3.200,0000	89,6667	376,5232	141.769,6901
1996	63	10,0000	1.700,0000	97,4921	226,8056	51.440,7701
1997	14	10,0000	3.200,0000	400,8571	847,5818	718.394,9011
1998	17	10,0000	1.000,0000	164,1176	228,9394	52.413,2353
1999	5	100,0000	100,0000	100,0000	0,0000	0,0000
Maximum Port Density (No of Ports)						
1990	39	4,0000	144,0000	36,9231	42,0622	1.769,2308
1991	33	8,0000	156,0000	32,2424	36,5813	1.338,1894
1992	85	4,0000	576,0000	60,7412	98,8551	9.772,3370
1993	55	8,0000	520,0000	76,7818	95,3234	9.086,5441
1994	50	6,0000	416,0000	55,6600	74,0581	5.484,5963
1995	72	6,0000	560,0000	49,3056	87,8465	7.717,0039
1996	63	4,0000	288,0000	42,8571	70,9477	5.033,5760
1997	14	6,0000	192,0000	34,5000	49,6739	2.467,5000
1998	17	4,0000	26,0000	15,7647	7,3103	53,4412
1999	5	8,0000	25,0000	17,0000	7,4162	55,0000
Minimum Configuration Equipment Price (thousands of US \$)						
1990	39	0,0033	0,7133	0,0594	0,1280	1637,7995
1991	33	0,0034	0,4800	0,0602	0,0961	923,9636
1992	85	0,0001	0,3706	0,0333	0,0570	324,8531
1993	55	0,0015	0,2375	0,0415	0,0496	246,4475
1994	50	0,0030	0,8562	0,0583	0,1284	1648,8490
1995	72	0,0013	0,1580	0,0269	0,0258	66,3646
1996	63	0,0020	0,9967	0,0730	0,1784	3183,3067
1997	14	0,0050	0,7992	0,1098	0,2392	5721,9228
1998	17	0,0008	0,1100	0,0182	0,0278	77,0838
1999	5	0,0050	0,0370	0,0134	0,0133	17,7479
Maximum Configuration Equipment Price (thousands of US \$)						
1990	39	0,0040	0,6900	0,1106	0,1452	2108,4808
1991	33	0,0050	0,8741	0,1615	0,2183	4763,8511
1992	85	0,0031	1,0320	0,0892	0,1589	2524,8031
1993	55	0,0043	2,8500	0,1702	0,4266	18200,5011
1994	50	0,0030	1,2294	0,1257	0,2473	6116,7480
1995	72	0,0013	0,4230	0,0554	0,0831	690,3481
1996	63	0,0020	5,5200	0,2706	0,9121	83199,1219
1997	14	0,0050	0,4153	0,0726	0,1105	1220,8433
1998	17	0,0008	0,1100	0,0238	0,0278	77,3576
1999	5	0,0100	0,0370	0,0194	0,0105	11,0368
Average Configuration Equipment Price (thousands of US \$)						
1990	39	0,0040	0,5250	0,0850	0,1195	1427,3192
1991	33	0,0050	0,5245	0,1108	0,1434	2057,6667
1992	85	0,0016	0,5629	0,0612	0,0981	961,6858
1993	55	0,0043	1,5438	0,1059	0,2319	5375,6489
1994	50	0,0030	0,6505	0,0920	0,1575	2481,1867
1995	72	0,0013	0,2142	0,0411	0,0474	224,5267
1996	63	0,0020	3,2583	0,1718	0,5324	28345,6069
1997	14	0,0050	0,4667	0,0912	0,1589	2524,8940
1998	17	0,0008	0,1100	0,0210	0,0276	75,9435
1999	5	0,0075	0,0370	0,0164	0,0118	14,0272

Table 3
Sample Statistics (Only Modular Configuration Hub Equipment)

Year	Sample Size	Minimum	Maximum	Mean	Std. Deviation	Variance
Backplane Capacity (Mbps)						
1990	3	120,0000	200,0000	156,6667	40,4145	1.633,3333
1991	11	100,0000	3.200,0000	824,0000	1.145,7260	1.312.688,0000
1992	9	100,0000	500,0000	151,1111	132,3296	17.511,1111
1993	22	0,0000	9.000,0000	1.703,5000	2.095,9457	4.392.988,3571
1994	17	10,0000	13.000,0000	2.959,1765	4.306,0467	18.542.038,0294
1995	8	100,0000	40.000,0000	9.700,2500	14.364,1395	206.328.503,3571
1996	18	10,0000	10.000,0000	3.790,1111	3.731,2654	13.922.341,3987
1997	15	800,0000	70.000,0000	10.572,0000	17.089,9700	292.067.074,2857
1998						
1999						
Maximum Port Density (No of Ports)						
1990	3	48,0000	120,0000	72,0000	41,5692	1.728,0000
1991	11	12,0000	336,0000	119,8182	88,7444	7.875,5636
1992	9	24,0000	256,0000	146,6667	77,4080	5.992,0000
1993	22	32,0000	672,0000	210,3636	162,3854	26.369,0043
1994	17	8,0000	504,0000	266,1176	141,1515	19.923,7353
1995	8	16,0000	768,0000	326,0000	222,2688	49.403,4286
1996	18	48,0000	576,0000	301,4444	171,1412	29.289,3203
1997	15	48,0000	504,0000	278,4000	157,1809	24.705,8286
1998						
1999						
Minimum Configuration Equipment Price (thousands of US \$)						
1990	3	0,0254	0,1728	0,0938	0,0742	551,1256
1991	11	0,0176	0,2250	0,1123	0,0733	537,1971
1992	9	0,0144	0,9800	0,1967	0,3124	9759,2439
1993	22	0,0106	0,6625	0,1332	0,1843	3395,7838
1994	17	0,0040	0,3943	0,1193	0,0869	755,5603
1995	8	0,0445	1,3744	0,4089	0,4764	22698,4188
1996	18	0,0545	6,0938	1,0909	1,4415	207787,6061
1997	15	0,0025	12,9718	1,6885	3,1886	1016737,7775
1998						
1999						
Maximum Configuration Equipment Price (thousands of US \$)						
1990	3	0,0396	0,4103	0,2860	0,2134	4556,0363
1991	11	0,1388	0,8250	0,4561	0,2564	6574,5731
1992	9	0,0440	0,4250	0,2046	0,1156	1336,5028
1993	22	0,0648	7,1682	1,2406	1,8833	354692,1082
1994	17	0,0040	5,2517	1,2568	1,2721	161827,0099
1995	8	0,3500	5,9486	1,9340	1,7872	319421,3043
1996	18	0,0349	8,3105	1,0412	2,0381	415383,3213
1997	15	0,0749	9,5501	1,3161	2,3377	546475,5306
1998						
1999						
Average Configuration Equipment Price (thousands of US \$)						
1990	3	0,0325	0,2905	0,1899	0,1381	1906,6753
1991	11	0,1029	0,5250	0,2842	0,1502	2255,5568
1992	9	0,0344	0,5600	0,2007	0,1627	2646,1449
1993	22	0,0432	3,6693	0,6869	0,9525	90720,8994
1994	17	0,0040	2,8230	0,6880	0,6629	43947,6331
1995	8	0,2125	3,1714	1,1714	0,8921	79590,3144
1996	18	0,0447	5,1385	1,0660	1,4366	206370,3741
1997	15	0,0575	6,5443	1,5023	1,8516	342842,9613
1998						
1999						

Table 4

Model A				
Dependent Variable: Ln(Price Max Config)				
SSE	478,05		F ratio	87,17
DFE	516			
MSE	0,9265		RSQ	0,7028
	Estimate		St Error	T Value
Intercept	5,281		0,1963	26,901
LBCAP	0,4343		0,0302	14,399
LMAXP	0,4889		0,046	10,634
TR Dummy	0,2892		0,1104	2,6194
Manag Dummy	0,6378		0,13	4,9044
Other Tech Dummy	-0,5782		0,1652	-3,5006
Time dummy 1991	-0,2425		0,2139	-1,134
Time dummy 1992	-0,8478		0,18	-4,7095
Time dummy 1993	-0,7257		0,192	-3,7797
Time dummy 1994	-0,6834		0,1938	-3,5269
Time dummy 1995	-0,8118		0,1869	-4,3429
Time dummy 1996	-0,8666		0,1913	-4,5304
Time dummy 1997	-0,9941		0,2619	-3,796
Time dummy 1998	-1,9514		0,2851	-6,8454
Time dummy 1999	-1,6668		0,4602	-3,6219

Significant Coefficients (95%) in Bold

Table 5

Model B			
Dependent Variable: Ln(Price Max Config)			
SSE	397,96	F ratio	23,831
DFE	470		
MSE	0,8467	RSQ	0,7526
	Estimate	St Error	T Value
Intercept	4,9516	0,3479	14,235
LBCAP	0,3629	0,0411	8,836
LMAXP	0,5098	0,0504	10,107
TR Dummy	0,3286	0,1201	2,7361
Manag Dummy	0,6803	0,1319	5,159
Other Tech Dummy	-0,5296	0,1953	-2,7115
Time dummy 1991	0,0478	0,4093	0,1167
Time dummy 1992	-0,1656	0,3885	-0,4264
Time dummy 1993	-0,2168	0,3981	-0,5446
Time dummy 1994	-0,3093	0,38	-0,8138
Time dummy 1995	-0,713	0,3646	-1,9552
Time dummy 1996	-0,2786	0,3602	-0,7734
Time dummy 1997	-0,3641	0,7191	-0,5064
Time dummy 1998	-1,8064	0,7713	-2,3419
Time dummy 1999	0,1797	0,9785	0,1837
Tech Class 2 by year 90	0,6705	0,3547	1,89
Tech Class 5 by year 90	-0,5454	0,7151	-0,7627
Tech Class 6 by year 90	1,41	1,1272	1,2509
Tech Class 1 by year 91	-0,6739	1,0075	-0,6689
Tech Class 2 by year 91	-0,4237	0,3071	-1,3796
Tech Class 3 by year 91	0,5912	1,1719	0,5045
Tech Class 5 by year 91	1,5443	0,3171	4,8707
Tech Class 6 by year 91	-1,1217	0,7147	-1,5694
Tech Class 5 by year 92	0,7412	0,2727	2,7181
Tech Class 2 by year 92	-0,4471	0,2731	-1,6368
Tech Class 3 by year 92	-0,0815	0,4066	-0,2005
Tech Class 6 by year 92	0,3914	0,7133	0,5488
Tech Class 1 by year 93	0,1166	0,306	0,3809
Tech Class 2 by year 93	-0,2421	0,278	-0,8708
Tech Class 3 by year 93	0,0056	0,3133	0,0177
Tech Class 5 by year 93	0,8131	0,3296	2,4666
Tech Class 6 by year 93	-0,4195	0,4599	-0,9122
Tech Class 1 by year 94	0,235	0,4005	0,5867
Tech Class 2 by year 94	-0,0028	0,2914	-0,0097
Tech Class 3 by year 94	0,1882	0,401	0,4692
Tech Class 5 by year 94	0,8439	0,3744	2,2539
Tech Class 6 by year 94	-0,8994	0,5425	-1,6577
Tech Class 1 by year 95	-0,0275	0,5639	-0,0488
Tech Class 2 by year 95	0,3861	0,2484	1,5542
Tech Class 3 by year 95	0,0791	0,5229	0,1512
Tech Class 8 by year 95	0,6097	0,4061	1,5012
Tech Class 6 by year 95	0,0916	0,6473	0,1415
Tech Class 1 by year 96	0,2623	0,3645	0,7197
Tech Class 2 by year 96	-0,2418	0,2638	-0,9164
Tech Class 3 by year 96	0,4348	0,309	1,4071
Tech Class 4 by year 96	-0,6149	0,5265	-1,1679
Tech Class 5 by year 96	0,7026	0,5097	1,3783
Tech Class 6 by year 96	-0,7148	0,5642	-1,2669
Tech Class 8 by year 96	-0,314	0,2724	-1,153
Tech Class 9 by year 96	0,4342	0,5215	0,8327
Tech Class 1 by year 97	1,0666	0,6951	1,5344
Tech Class 2 by year 97	-0,1333	0,5655	-0,2357
Tech Class 3 by year 97	-1,1371	1,4066	-0,8084

Tech Class 5 by year 97	1,2695	1,3436	0,9448
Tech Class 8 by year 97	-0,5549	0,6377	-0,8702
Tech Class 9 by year 97	-0,4232	0,4935	-0,8577
Tech Class 2 by year 98	0,5485	0,4952	1,1076
Tech Class 3 by year 98	-2,0978	1,231	-1,7041
Tech Class 8 by year 98	0,0709	0,7124	0,0995
Tech Class 9 by year 98	1,8209	0,9916	1,8364
Tech Class 2 by year 99	-1,5998	1,0373	-1,5423

Significant Coefficients (95%) in Bold

Table 6

Model B'				
Dependent Variable: Ln(Price Max Config)				
SSE	445,01		F ratio	74,38
DFE	512			
MSE	0,8692		RSQ	0,7234
	Estimate		St Error	T Values
Intercept	5,4478		0,1933	28,19
LBCAP	0,3621		0,0322	11,231
LMAXP	0,5172		0,0448	11,532
TR Dummy	0,3117		0,1074	2,9021
Manag Dummy	0,592		0,1265	4,6811
Other Tech Dummy	-0,3944		0,1645	-2,3974
Time dummy 1991	-0,7791		0,2438	-3,1959
Time dummy 1992	-1,0107		0,1801	-5,6115
Time dummy 1993	-0,8368		0,1987	-4,2119
Time dummy 1994	-0,7367		0,1969	-3,7409
Time dummy 1995	-0,7942		0,1811	-4,3848
Time dummy 1996	-0,815		0,1857	-4,3901
Time dummy 1997	-0,8812		0,2551	-3,4549
Time dummy 1998	-1,8311		0,277	-6,6113
Time dummy 1999	-1,5421		0,4463	-3,4554
Tech Class 5 by year 91	1,3424		0,2954	4,5446
Tech Class 5 by year 92	0,9352		0,2499	3,7416
Tech Class 5 by year 93	0,5874		0,2476	2,3722
Tech Class 5 by year 94	0,4329		0,2808	1,5418

Significant Coefficients (95%) in Bold