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Analysis of Product Upgrades in Computer Software

by

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ABSTRACT

This thesis examines the effects of both intra-brand upgrades and inter-brand upgrades in product markets that are characterised by network externalities, switching costs, and rapid technological progress.

Prior research indicates that there can be significant inefficiencies in markets with network externalities, such as inefficient standardisation, incorrect standardisation, and inefficient fragmentation of standards. This paper analyses the impact of inter-brand upgrades and concludes that there can be two new inefficiencies: *delayed* incorrect standardisation and *delayed* inefficient standardisation.

The actual scope of the welfare improvement is inversely related to the cost of switching between brands. As the switching cost decreases, an inter-brand upgrade strategy becomes more profitable for the *ex post* superior technology because the upgrade can be used to capture users of older, competing technologies. At the same time, an inter-brand upgrade solution is more likely to be socially optimal because the users of the older technology can participate in technological progress.

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1 INTRODUCTION

This paper modifies the existing literature on network externalities to more accurately describe the computer software industry. Network externality literature applies to the computer software industry because, all other things equal, consumers prefer to be part of a network of fellow consumers who use the same product. When consumers derive value from the software if other consumers use it, the addition of one more user will not only benefit the individual, but everyone else that uses the same program. The individual does not account for this, so the societal benefit of her purchase is much greater than her own private benefit. Consequently, there is significant potential for market failure because not enough people will buy into the network in order to maximise societal welfare.

Because of network externalities, the computer software market can be prone to 'tipping' in favour of one product. This is especially true for applications such as word processors and spreadsheets where, due to the small quality differences between the competing products, there is little room for a 'niche' market. Early stages of competition will be fierce as firms bid for future monopoly profits by doing things to increase the size of the installed base and influence consumers' expectations of both future quality and network size. Microsoft Corporation could be accused of using such a strategy by distributing free copies of its Internet browser and allowing ordinary consumers to freely use copies of software applications still in the testing phase (known as "Beta" versions).

Upgrades, and particularly upgrades designed for users of competing products (hereafter called competitive upgrades), also influence expectations about installed base since they bridge the gap between an obsolete (but still functional) technology and the newest technology. Without upgrades, the adoption of a new technology may be slowed because users of the older technology value the improvement less than new consumers value it. Thus, the ability to use the upgrade for the purpose of price discrimination as well as the affect on aiding technological progress will benefit both the firm and consumers. Additionally, since the upgrade allows everyone to use the same technology, all consumers will benefit from the network externality that is generated.

This paper is based on Katz and Shapiro (1986), who create a model that uses a two-stage game that shows how two firms strategically compete with incompatible and evolving technologies. Within this model, it is assumed that the first firm provides an established technology that is mature and does not evolve. The other firm provides a technology which is widely recognised to be superior in the future, but is inferior to the established technology at present. Two generations of homogenous consumers purchase these technologies; the first generation of consumers enters the market in the first period and chooses between the established or emerging technology, while in the second period, the second generation of consumers enters the market. Both generations of consumers value quality but will choose the inferior product if it provides a sufficient network benefit.

When each of the firms has proprietary control over their own technology, strategic pricing on behalf of the firms backing these technologies may have the effect of partially internalising the externality. Both firms can use the profits they expect in the future to finance competition today, which has the effect of transferring future profits to subsidise competition in the present. By charging a price above cost for late adopters to subsidise competition for early adopters, the firm compensates early adopters for the network benefit they confer on the late adopters. This partially internalises the network externality and increases the chances of standardisation. Katz and Shapiro also show that, in the event of standardisation, the *ex post* superior technology has the potential to extract more surplus from the second generation because it provides a more valuable product. This 'second-mover' advantage creates two new inefficiencies because the firm backing the *ex post* superior technology may find it profit maximising to sell to early generation of consumers when it is not socially optimal to do so. If this leads to standardisation on the *ex post* superior technology when there should be fragmentation, it is called *inefficient standardisation*; if there should be standardisation on the *ex post* inferior technology, it is called *incorrect standardisation*.

The purpose of this paper is to outline when competitive upgrades create an efficient outcome and when they do not. This is proved by using a model that is very similar to Katz and Shapiro with the exception that the first generation may delay their purchase until the second period, or if they do purchase in the first period, they can purchase an upgrade later. The resulting market equilibrium shows increased instances of standardising on the *ex post* superior technology, both from a market perspective and the social optimum.

The firm supplying the *ex post* superior technology has two methods to capture the entire market. For low rates of technological progress and/or high values of the switching cost, it will choose a strategic pricing strategy, just as in Katz and Shapiro (1986). By committing profits that it extracts from latter generation in the second period to subsidise competition in the first period, it can sell to consumers in the first period despite its quality disadvantage. This way, by making sure that the first generation does not purchase the competing technology, the firm avoids having to lower its competitive upgrade price to compensate the first generation for switching. By charging a price above cost for latter generation and a price below cost for first generation, it is compensating first generation for the positive effects they will have on the latter generation' network benefit. This partially internalises the externality and increases the instances of standardisation. Generally speaking, under the same conditions of low technological progress and high switching costs, this is also socially optimal because it costs the first generation very little in terms of using an inferior product in the beginning. However, much of the original Katz and Shapiro inefficiencies still apply.

For high rates of technological progress and/or low values of the switching cost, competitive upgrades are more likely to be used. Under a similar situation to the above, the firm could wait until the second period and offer a competitive upgrade to the first generation who use the established technology. Offering the competitive upgrade in the second period benefits the firm because for high rates of technological progress or low switching costs, it does not have to compete in the first period with an inferior product. Additionally, by offering a competitive upgrade, it is doing something very similar to the strategic pricing case. If the first generation switches brands, there is a positive network effect on the second generation. The firm can appropriate some of this surplus to subsidise the offering of the competitive upgrade. This partially internalises the externality and increases the instances of standardisation. The competitive upgrade also benefits the consumer since she can use the most up-to-date product in each period. Thus, in many cases, competitive upgrades enhance welfare because both the market outcome in-line and the socially optimal outcome are the same.

However, in some cases, competitive upgrades are not welfare enhancing. This occurs when the switching cost is low enough to make competitive upgrades the profit maximising strategy for the firm. However, from a welfare perspective, the rate of technological progress is not high enough to justify the first generation's switch to the *ex post* superior technology.

It is profit maximising for the firm to offer competitive upgrades for the following reasons: first, the rate of technological progress is high enough such that the firm backing the *ex post* superior technology can always profitably sell to the latter generation. Additionally, the firm knows that the latter generation's willingness to pay will dramatically increase if the first generation uses the same technology. With the surplus it can extract from the latter generation, it can afford to subsidise the competitive upgrade, sometimes for a price that is below cost,.

The welfare implication of this is that technological progress is not high enough relative to the switching cost to provide justification for the first generation to switch technologies. If the network benefit is small, then the latter generation should use the *ex* *post* superior technology and the result is *delayed* inefficient standardisation. This is similar to Katz and Shapiro's inefficient standardisation because the *ex post* technology's second-mover advantage causes standardisation when there should be fragmentation. The only difference between the two is that delayed inefficient standardisation occurs in the second period instead of the first. If the network benefit is large, then the latter generation should use the *ex post* inferior technology because it is the same technology that the first generation uses. This is called *delayed* incorrect standardisation because it is very similar to Katz and Shapiro's incorrect standardisation. It is similar because the *ex post* superior technology's second-mover advantage creates standardisation on the wrong technology. Just as in the case of delayed inefficient standardisation, the only difference is that *delayed* incorrect standardisation occurs in the second period instead of the first.

To reach this conclusion, Chapter 2 will undertake a more detailed survey of the literature on this, and related topics. This chapter will pay particular attention to how previous authors have dealt with network effects, technological progress, incompatible technologies, and upgrades. Some authors, such as Katz and Shapiro (1986), Thum (1994), and Choi and Thum (1998), focus on the strategic behaviour of firms and how they use tools such as strategic pricing and upgrades to gain a competitive advantage. Other authors, such as Farrell and Saloner (1992) and Choi (1996), focus on how consumers choose between incompatible technologies and how they react to other influences, such as converters. Finally, authors such as Fudenberg and Tirole (1998), Lee and Lee (1998), and Bensaid and Lesne (1996) deal with how a firm that sells a durable good can avoid competing with the second-hand market of its own product by, among other things, introducing obsolescence via technological innovation.

Chapter 3 will then outline the assumptions of the competitive upgrade model before developing the socially optimal outcome (Section 3.3) by which the market outcome can be judged. Chapter 4 will then develop a benchmark to analyse the effects of competitive upgrades by first assuming that the competitive upgrade option is not available to the firm and Chapter 5 will remove this assumption. Finally, Chapter 6 compares the market outcome with and without competitive upgrades.

2 LITERATURE REVIEW

The relevant literature on upgrades, network effects, and intertemporal substitution will either focus on how firms compete or how consumers choose what or when to purchase. Literature focusing on the supply-side tends to focus on the strategic interaction between two network technologies from the beginning to the end of the product's life cycle. These papers generally have the goal of understanding the dynamics of which technology will be adopted as a result of the strategic interactions between firms and thus, may make the simplifying assumption that consumers are homogenous. Literature focusing on the demand-side of the market instead models how consumers make the transition between technologies. In this case, the emphasis on the adoption decision means that consumers are often assumed to be heterogeneous in taste. Such consumers are faced with the dilemma of choosing between a network and a more preferred product. If they choose the technology without the large installed base, consumers may also have the opportunity to purchase a converter. The converter will be able to access the network, but with some degradation of quality. Finally, literature focusing on intertemporal substitution models the consumer's choice as to when she should purchase. The durable nature of computer software means that the firm must be aware of an existing stock of its own product as it sells its product over successive time periods. Therefore, any incentives the firm has to change its price over time will be known to rational early generations and this will have an effect on the adoption of the technology. Papers focusing on the supply-side of the market will be covered first.

2.1 STRATEGIC BEHAVIOUR OF FIRMS

Papers focusing on the supply-side of the market include Katz and Shapiro (1986), Thum (1994), and Choi and Thum (1998). All have several common features. Each uses a two-stage game in which two incompatible technologies that exhibit network externalities will compete for market share. These models usually state an equilibrium as a function of relative technological leads and the most interesting case is inevitably where the technological lead changes from one period to the next. Purchasing these technologies are two generations of homogenous consumers who derive utility from the stand-alone value of the technology as well as how many others ultimately use the same brand. Additionally, all of the papers discussed here will assume that there is no uncertainty and consumers can rationally expect the actions of others will be optimal. Therefore, the first generation of consumers (early adopters) recognise that the consumption decisions of the second generation of consumers (late adopters) must be optimal for whatever the early adopters do in the first period.

2.1.1 KATZ AND SHAPIRO (1986)

The main objective of Katz and Shapiro is to examine how an industry with network externalities is effected by property rights[1]. Therefore, the model is set up to compare the market outcome under three different scenarios: when neither technology is sponsored, when one technology is sponsored, and when both technologies are sponsored. In addition, it is assumed that early adopters may not delay their purchase and that they cannot purchase again in the second period.

If neither technology is sponsored, it is assumed that free entry will result in each technology being produced by many competitive firms; consequently, both of the technologies will be available to consumers at marginal cost. If the technological lead changes from one period to the next, Katz and Shapiro highlight two important issues. First, for high rates of technological progress, there will be inefficient fragmentation. This result occurs because of the network externality as each consumer will evaluate their own individual network benefit and ignore their impact on everyone else. Thus, the total benefit of one more consumer joining the network will be less than the private benefit and the total network size will be too small.

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[1] Katz and Shapiro introduce the term 'sponsor' to refer to a single firm that holds property rights to a given technology.

The second issue is that there will be incorrect standardisation of the old technology when technological progress is low. This is also because early adopters purchase without considering the effects on late adopters. If the rate of technological progress is low, then early adopters may decide that using the *ex post* superior technology may not be worth committing to, if it means using an inferior product in the first period. Once early adopters purchase the established technology, late adopters in the second period are faced with either purchasing the superior technology or purchasing an inferior technology that has an installed base. However, because of a low rate of technology progress, the quality improvement will be negligible and with the network benefit taken into account, late adopters will find the *ex post* inferior technology more attractive. Therefore, standardisation on the wrong technology may occur.

If only one of the technologies is sponsored, the inefficient fragmentation is significantly reduced. The firm backing the sponsored technology can expect that if the unsponsored technology is not purchased in the first period, it will be at a disadvantage in the second period because it will not have an installed base of early adopters to attract late adopters[2]. This will leave the sponsoring firm facing less competition and a greater opportunity to appropriate consumer surplus in the process. Therefore, the sponsoring

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[2] This is given the term 'weakened rival effect' by Katz and Shapiro.

firm can use this expectation of future profit to its advantage by strategically pricing in the first period. Where the unsponsored technology can only price as low as marginal cost in the first period, the sponsored technology can price below that, even if it means going below its own cost. It will be willing to do this as long as the losses in the first period are not greater than the expected profits in the second period. This is so effective that the sponsored technology will often capture the entire market even if everyone agrees that the unsponsored technology is superior. This creates a new bias toward standardising on the sponsored technology.

This outcome occurs because the sponsored technology can internalise some of the network externality. By pricing below cost in the first period and above cost in the second period, it is essentially transferring some of the benefits of standardisation from the late adopters to the early adopters. This transfer is a private benefit, not a social benefit, of the sponsored technology winning in the first period; it allows early adopters to be partially compensated for the benefit they confer on late adopters by increasing the network size.

Finally, if both of the competing standards are sponsored, the incidence of inefficient fragmentation shrinks because of a bias toward the *ex post* superior technology, called a 'second-mover' advantage. The second-mover advantage leads to inefficient standardisation and incorrect standardisation. This occurs in much the same way as the bias toward the sponsored technology in the previous case. While both firms can charge prices that deviate from marginal cost, the *ex post* superior technology can out-price the *ex post* inferior technology because its product will be superior in the second period. Installed base issues aside, the *ex post* superior technology will have a greater stand-alone value in the second period. Therefore, if it were to win in the first period, it can expect even more profits than its competitor, should it have won in the first period.

This second-mover advantage result is new in the sense that previous works had always asserted a bias toward the *ex post* inferior technology, or a 'first mover' advantage. Katz and Shapiro do show that inefficient fragmentation and standardisation on the *ex post* inferior technology are possible, but are less likely to occur because of sponsorship.

Competitive upgrades enhance this second-mover advantage, but ironically, this leads to a more efficient outcome. The competitive upgrade allows early adopters to use the best product available at the moment, allowing them to participate in technological progress. Also, for high rates of technological progress, this allows standardisation where without the ability to switch brands, the best possible outcome would have meant forfeiting the network benefits and fragmenting. However, because early adopters must learn a new technology, the competitive upgrade outcome is only optimal when the benefits of switching (i.e. the quality gain for early adopters or the network benefit from standardising) are greater than the switching cost. The same principles apply to the profit maximising strategy of the firm backing the *ex post* superior technology. Since the willingness to pay of consumers will be effected by the same three variables (technological progress, network benefits, and switching costs), so too will the firm's profitability. If technological progress and network benefits are large relative to the switching cost, then offering a competitive upgrade will be the most profitable strategy for the firm. The high rate of technological progress means that the cost of subsidising competition in the first period will be high and early adopters will have a high willingness to pay for the competitive upgrade net of the switching cost. Also, large network benefits will mean that all consumers will have an increased willingness to pay for a product that everyone uses.

2.1.2 THUM (1994)

Thum uses the Katz and Shapiro (1986) framework to examine how the option for first period consumers to purchase again in the second period will affect what types of contracts the firm will offer. Therefore, Thum modifies the starting assumptions to allow for repeat purchases within the *same* technology and to recognise the fact that consumers may wish to participate in the advances of products they have purchased before. Further, it is assumed that there is both forward and backward compatibility between the new and the old product, and that early adopters do not have the opportunity to defer their purchase until the second period.

Thum examines the market outcome under three different sets of contracts. First, if price discrimination is not possible, the firm is limited to offering simple market contracts because it has no means to differentiate between new customers and repeat customers. Thus, in the second period, a firm may try to sell to both groups of consumers by offering a price equal to the lowest willingness to pay, or sell to one group by offering a price equal to the valuation of the group with the highest willingness to pay. Secondly, if price discrimination is possible (i.e. early adopters can trade in their old version for a new one), the firm will be able to sell to the early adopters with an update contract and sell to the late adopters with a simple market contract. Finally, the firm could also offer a service contract to the early adopters in the first period. The price of this service contract would include payment for all future versions up front.

Thum uses the simple market contract outcome, where early adopters may make repeat purchases, as a benchmark, to compare update contracts and service contracts. The simple market contract result is similar to Katz and Shapiro (1986) as the inefficiencies of non-standardisation and standardising on the wrong technology still exist for the same reasons. In addition to this, however, there is one new point to make. If the rate of technological progress is low, it is possible for the older generation to be inefficiently excluded from using the new technology in the second period. This occurs because the new technology will not be much different than what early adopters already use. Consequently, late adopters will be willing to pay much more for the new version than would the early adopters. With only simple market contracts available to the firm, it will be more profitable to offer a price equal to the late adopters' willingness to pay. This will effectively prevent early adopters from accessing the new technology.

Since the benchmark in this model is one where early adopters may make repeat purchases, the effects of update contracts in this context are limited to the benefits of price discrimination. Without update contracts, early adopters faced the same price as late adopters for the new technology, despite the fact that they have a different willingness to pay. If early adopters have a significantly lower willingness to pay, the firm may find it more profitable (given equal population sizes) to offer a price that is solely meant for late adopters. This excludes early adopters from technology progress, whereas if update contracts are offered, the firm can increase profits by also selling to this market segment. However, because the update contract only allows the firm to increase its profits if consumers start by using its own brand, the firm is constrained in the prices it can charge to these consumers. The first generation will not purchase in the first place if they know that the firm will charge and update contract that is greater than their *ex ante* valuation of the product. Thus, it will not be able to use its update contract profits to further subsidise competition for the first generation. Therefore, upgrades in this paper do not alter the competitive behaviour of firms, so there is no effect on the second-mover advantage and no effect on inefficient standardisation or incorrect standardisation.

Next, Thum examines the case where both firms offer service contracts. Because service contracts also upgrade the early adopters, this will eliminate the case where early adopters want to acquire the new technology but are unwilling to pay as high of a price as the late adopters. In addition to this welfare improvement, service contracts will also reduce the instances of inefficient non-standardisation. Because the service contract includes not only today's product, but all future versions of it, early adopters' willingness to pay will be much higher for the *ex post* superior technology. Therefore, the firm backing the *ex post* superior technology can appropriate some of this consumer surplus to subsidise competition in the second period. This transfer internalises the network externality by compensating late adopters for the benefit they confer on the early adopters. However, as one might expect, this will also strengthen the bias toward the *ex post* superior technology (and therefore, the second-mover advantage) to the point of occasionally causing standardisation on the wrong technology.

Finally, the type of contact that will prevail in equilibrium is found by allowing the firms to choose not only prices, but also the type of contract. Fortunately, this analysis is simplified by noting that update contracts will always dominate simple market contracts. Competition between firms does not change between simple market and update contracts because update contracts are fundamentally different only when both consumer groups use the same technology. In this case, profits (and total societal welfare) are higher with update contracts.

Competition between update and service contracts is more complicated because each contract can be superior depending on market conditions. If the technological lead changes modestly, it is most profitable for the firm to sell to both consumer groups. Thus, service contracts will dominate because with an update contract, the firm has the option of selling the update to the early adopters later. Therefore, with the update contract, the firm cannot commit to charging a higher price for early adopters to transfer to the late adopters because early adopters will be able to avoid this high price by practising arbitrage and purchasing the product intended for the late adopters. However, with a service contract the firm will be able to commit to a lower price in the second period because the early adopters' update is already paid for. This will increase the instances of standardisation, increase profits and improve welfare.

If the technological lead changes dramatically, it would be socially optimal for the early adopters to use the better product in the first period. Therefore, the market should fragment. While service contracts will create standardisation in this case, but firms will not use them because update contracts will be more profitable. The high rate of technological progress means that subsidising the adoption of one generation of consumers with the profits extracted from another generation is less profitable than concentrating on one generation of consumers and extracting all of their surplus. Therefore, the firm backing the *ex post* inferior technology will sell to the early adopters (as well as selling them an upgrade in the second period) and the firm backing the *ex post* superior technology will sell to the late adopters. Thus, the market efficiently fragments.

However, as Thum points out, competition between the three types of contracts may not be possible in practice because of a moral hazard problem. Once the firm sells a service contract, it will have incentive to decrease its innovation effort to maximise profits. Unless the technology and its future improvements are exogenously given and perfectly observable, consumers will not accept a service contract. Indeed, the only cases where we observe such contracts in the computer software industry are in applications such as virus checkers and accounting software, where necessary improvements to the program are measurable.

The model presented in this paper does not obtain the same result as the Thum paper because Thum uses a different benchmark to analyse the effects of upgrades. By assuming that early adopters will make repeat purchases in the base case, the introduction of an upgrade will only serve to help customers whose lower willingness to pay would otherwise discourage them from purchasing. Therefore, Thum finds that intra-band upgrades have no effect on what technology is ultimately chosen. However, using Katz and Shapiro's (1986) model as a benchmark against upgrades shows the full effect. The fact that early adopters may upgrade to the new technology makes it more valuable to them. This not only favours the *ex post* superior technology as a social optimum, but because the firm can profit from this increased willingness to pay, it will also influence the market outcome. Thus, upgrades increase the instances of standardisation on the *ex post* superior technology. This has an effect on inefficient fragmentation because the implication is that standardisation on the *ex post* inferior technology is less desirable as a social optimum and fragmentation is no longer as profitable for the firm backing the *ex post* superior technology.

2.1.3 CHOI AND THUM (1998)

Choi and Thum (1998) modify the Katz and Shapiro (1986) framework to analyse the effects of permitting early adopters to defer their purchase until the second period.

This paper assumes that the two technologies arrive sequentially to the market such that the *ex post* inferior technology faces no competition in the first period. It is also assumed that consumers are not permitted to make repeat purchases, but they can defer their decision to purchase until the *ex post* superior technology has evolved.

Choi and Thum compare the perfect competition outcome with an outcome involving sponsorship, but also add one more case: the sponsored (i.e. patent protected) technology may license out its technology to other firms. In this instance, the developer of the product sells a licensing contract before the start of the first period in which buyers of this contract may sell the technology in exchange for a royalty. In the second period, the developer and the other licensed suppliers will compete until the price falls to a level equal to the royalty rate.

In a perfectly competitive situation, Choi and Thum find three possible inefficient outcomes. First, when technological progress is high, there is the 'traditional' non-standardisation outcome in which late adopters ignore the possible network benefit that could have accrued to early adopters if they had chosen the same technology. Second, for cases of very high technological progress, early adopters should wait until the second period to adopt the new and improved technology. However, because the early adopters' *private* benefit of waiting until the second period (equal to the benefit of using the new technology plus the private network benefit) is less than the social benefit, early adopters will too often purchase the *ex post* inferior technology in the first period. Additionally, if the network benefit is also strong, there will be a third inefficiency. The late adopters, having observed the early adopters purchasing the *ex post* inferior technology, will also purchase the *ex post* inferior technology to take advantage of the network benefit. This will cause standardisation on the wrong technology.

When the *ex post* superior technology is sponsored, this inefficiency of too little waiting on behalf of early adopters will become worse. Thus, it will also increase the likelihood that there will be standardisation on the wrong technology. This is because the early adopters know that foregoing the opportunity to purchase in the first period will mean that the *ex post* inferior technology will compete in the second period without an installed base. With a weakened competitor, the holder of the *ex post* superior technology will have much more power to mark up prices. Thus, rational consumers know that they will face a higher price for this technology in the future, so they avoid the emerging technology altogether and stay with the established technology.

A way in which the firm sponsoring the emerging technology can combat this bias is to licence out its technology in the second period. This has the purpose of committing to a second period price (equal to the royalty rate) that is lower than what it would be under sponsorship. This commitment to not charge as high a price will bring the outcome closer to that of perfect competition, but because the royalty rate will never be less than cost[3], the licensing outcome would never be better than the perfect competition outcome.

Additionally, the *ex post* inferior technology can defend against licensing if it also is sponsored. By licensing out its technology in the second period, it can set a very low (or negative) royalty rate that will cause the second period price to fall below cost. The firm can do this because knowing that late adopters will purchase the established technology in the second period, early adopters will be willing to purchase at a price above cost in the first period. Early adopters know that a guaranteed low price in the second period will attract the late adopters to the network and ensure a higher network benefit for them in the second period.

Thus, Choi and Thum contend that, unlike the conclusions of Katz and Shapiro (1986) and this paper, there is a bias towards the *ex post* inferior or established technology, if we assume that consumers may delay their purchase. However, this reversal cannot be entirely attributed to consumers' option to wait because Choi and

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[3] Recall that this is the *ex post*-superior technology's only chance to compete: it will not be willing to price below cost.

Thum impose one additional, but key, assumption. The *ex post* superior technology may not enter competition in the present, even with an inferior product. If such an assumption is removed, as it is in this paper, such a result is not duplicated. In fact, when the *ex post* superior technology is assumed to compete in the first period, the bias remains as it did in Katz and Shapiro (1986).

The competitive upgrade model does not rule out first period competition. It finds that by allowing the *ex post* superior technology to be available in the first period, it will never be socially optimal for early adopters to delay their purchase. This is because using the *ex post* superior technology in the first period and upgrading later is always preferred to waiting to buy the *ex post* superior technology in the second period. Additionally, it is rare that early adopters would ever prefer to wait until the second period because price competition between the two firms in the first period means that consumer surplus is high.

2.2 ADOPTION CHOICE

Papers that consider the demand-side perspective include Farrell and Saloner (1992) and Choi (1996). They do not necessarily use a multi-stage game or assume that consumers have homogenous preferences. Instead, consumers face a choice between two technologies. Given equal network sizes each consumer will have a clear preference for one technology based on its intrinsic value. However, because of the value associated with a large installed base, consumers may be tempted to purchase the alternative technology. In this case, they may have the opportunity to purchase a converter that will be able to access the other network. This converter is assumed to be imperfect and can only be used with some degradation of quality, hence only a portion of network benefits will be accessible through the converter. It is assumed that the converters are exogenously supplied and available at cost. This is very similar to the concept of upgrades because an imperfect converter functions much like a competitive upgrade in which the consumer incurs a cost to learn the new technology.

2.2.1 FARRELL AND SALONER (1992)

Farrell and Saloner ask if converters can provide compatibility without constraining variety or innovation under conditions of perfect competition, monopoly.

and duopoly. To do so, Hotelling's horizontal differentiation framework is used (Hotelling 1929). Farrell and Saloner give consumers a choice between two technologies that, without a converter, are incompatible. It is assumed that consumers are heterogeneous in their preferences and that their preference can be represented as a location on a unit interval. With the firms located at the end points on this interval, consumers will have a locational preference the closest technologies but will also derive some benefit from being part of a network. Therefore, consumers will have to make a choice between compatibility and their preferred brand.

The converter itself is assumed to work both ways. In other words, if consumers of technology A purchase a converter to access some of the network benefits of technology B, the users of technology B will also enjoy some of the network benefits of technology A. Whether the A or the B users will purchase this converter is unknown, but to avoid a discussion of a co-ordination problem it is assumed that consumers of the smaller network will make this purchase. The ultimate goal is to focus the analysis on the dominant firm's possible incentive to manipulate interface standards, but in the meantime, it is assumed that converters are supplied at a price equal to marginal cost.

Farrell and Saloner also make the point that there will never be a result in which 50% of consumers use one technology and 50% use another. This is proven by assuming the equilibrium is a '50-50' solution and examining the utility of a consumer close to the midpoint who purchases a converter. Such a person would not be using her preferred technology, but the savings from not having to purchase a converter will mean the net change in utility will be positive. Thus, provided the converter is priced greater than zero, no equilibrium involving the use of converters will be symmetric.

Under perfect competition, Farrell and Saloner find that there are two possible inefficient outcomes. First, an equilibrium involving the use of converters will occur too often. This is because the converter will lower the private cost to the consumer of not standardising. When consumers no longer risk losing the entire network benefit by choosing their preferred technology, they will be much more 'risky' in their behaviour. Second, when a converter equilibrium does occur, too many consumers use a converter rather than joining the dominant network. This happens because the private benefit of using a converter to access the network is greater than the societal benefit of using a converter. Since the social benefit of using a converter is less than the social benefit of buying directly into the dominant technology, too many converters will be used.

If a monopolist were to supply both of the technologies, it would seem that the firm could charge a set of prices such that it is less tempting for consumers to forego the network in favour of the other technology. However, this is not the case because it is in the monopolist's best interests to do otherwise. In fact, it is found that under a monopoly, an outcome involving converters is more frequent than under perfect competition. This is proven by imagining a perfectly competitive outcome where only one product dominates (one firm can attract all buyers with a price equal to marginal cost) and handing over control of the two technologies to a single firm. The monopolist cannot price discriminate and charge a price that is a decreasing function of how 'far' a consumer is from the firm's location, but it can increase its profit another way. By raising the price slightly, the monopolist could extract more surplus from the inframarginal consumers. Additionally, it could pick up the lost customers by lowering the price on the other product and selling it with a converter. Thus, there will be more non-standardisation outcomes under a monopoly situation.

In a duopoly situation, a converter outcome will be even more frequent than under a monopoly situation. While the monopolist would raise price to maximise profits on the inframarginal consumer, it would also incur a cost in that it would have to supply converters for the consumers it lost. In a duopoly situation, the firm supplying the dominant[4] technology does not incur the cost of supplying the converter, rather it is assumed this responsibility falls to the supplier of the non-dominant technology.

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[4] Remember that it has already been established that for a converter price greater than zero, one technology will always be dominant.

Therefore, the dominant technology supplier will be willing to raise the price even higher than a monopolist. This will result in even more consumers using converters than under perfect competition and monopoly situations.

Two interesting conclusions can also be derived from the duopoly situation. The first is that the dominant firm would prefer expensive converters because they increase the consumers' willingness to pay for the dominant standard (which does not require a converter). The second result is that all parties prefer efficient converters. For consumers, efficient converters will increase network benefits. For the firms, efficient converters mean that they will not need to compete as fiercely for market share because efficient converters weaken the link between the value of the product and how many other people use the same product.

While the inefficiencies identified in this paper are important, a model with competitive upgrades will not show identical results. Imperfect converters are similar to competitive upgrades with a switching cost in that network benefits are achieved at a cost. However, unlike the converter outcome, the competitive upgrade outcome means that all consumers are using the same technology. In the event of fragmentation in the Katz and Shapiro (1986) model, if early adopters were to acquire converters, they would still be using an old technology. In contrast, if the same early adopters were to acquire a competitive upgrade, they would be using the new technology. Provided that the price of the competitive upgrade is approximately equal to the price of the converter, early adopters would be better off with the competitive upgrade because they would receive the benefits of the new technology, not just accessing the network of the new technology. Therefore, it is possible that a competitive upgrade outcome will have exactly the opposite effect on welfare.

2.2.2 CHOI (1996)

The model by Choi tackles the common presumption that converters will help a new technology gain momentum because they reduce the loss of compatibility with the installed base. Choi takes a slightly different approach to this problem than Farrell and Saloner (1992) by not using the locational preference framework. Instead, Choi sets up the model by assuming that a stream of continuously arriving consumers must choose between an established technology that already has an installed base and a new technology that does not. To analyse the transition between the two incompatible technologies, Choi examines the choice of the first consumer to arrive after the release of the new technology. The consumer's decision is made knowing that a converter will be available.

While it is established that converters will increase welfare if they are introduced after all adoption decisions are made (i.e. converters arrive unexpectedly), Choi finds that if consumers know converters are available, it will have an effect on the adoption behaviour of consumers. Therefore, converters may or may not improve welfare. For example, if the old technology has a large installed base, consumers may be hesitant to purchase a new technology without the added security of a converter. This will result in an inefficient outcome if the rate of technological progress is high. In this case, converters change the adoption behaviour of consumers because they know they can adopt the new technology without completely giving up access to the installed base of the old technology. However, if the rate of technological progress is lower, consumers will continue this behaviour even if it is no longer socially optimal to adopt the new technology. In this case, the fact that consumers do not have to give up access to the old technology's installed base convinces them to try the new technology when from a welfare perspective, the new technology is not enough of an improvement to justify switching.

Choi also finds that converters have another effect on the behaviour of consumers. This occurs when consumers expect the new technology will be adopted by everyone else despite the fact that the rate of technological progress is low (or possibly negative). Without converters, the new technology will be adopted when it should not.

but when converters are available, consumers will stick with the old technology. With a converter available, the consumer is safe to adopt the old technology without the fear of being stranded. Since each successive consumer has the same choice, no one will adopt the new technology; the bandwagon for the new technology will never get started and welfare will improve.

The model with competitive upgrades will also show a bias toward the *ex post* superior technology because the risks of losing access to the installed base are reduced to nothing. However, unlike the introduction of converters, the introduction of competitive upgrades actually decreases the instances of the bias in cases of low rates of technological progress. Without competitive upgrades, the *ex post* superior technology often subsidises competition in the first period with expected profits from the second period and will bias the equilibrium in favour of the *ex post* superior technology. However, competitive upgrades create an opportunity for the firm to capture the entire market in the second period. Thus, the firm can cross-subsidise within the second period instead of between periods by using profits it earns from the late adopters to charge a lower price for the competitive upgrade. Competitive upgrades increase the chances of the *ex post* superior technology entering competition in the second period instead of the first.

The instances of converters improving welfare by slowing down the rate of technological progress are not comparable. In the Choi model, this occurs when the new technology is expected to be adopted by others in the future for reasons that are exogenous to the model. The competitive upgrade model that is presented in the next chapter does not allow such cases by the assumption that consumers will converge on the outcome that is Pareto preferred. In other words, if equilibrium occurs because each generation expects the other to choose a particular technology, it is assumed that the equilibrium will be on the *ex post* superior technology. This will avoid the need to discuss multiple equilibria. By construction, there will be no such cases of inefficiency arising from early adopters choosing the wrong technology because they believe late adopters will do the same.

2.3 DURABLE GOODS MONOPOLIST LITERATURE

Another approach to modelling upgrades is from the durable goods monopolist perspective. This group of papers focuses on intertemporal price discrimination and the Coase conjecture (Coase 1972). The premise behind the Coase conjecture is that a durable goods monopolist, selling identical products from period to period, must sell at marginal cost. Ideally, the monopolist would like to intertemporally price discriminate by charging a high price today and gradually decrease it over time. Doing this would extract all consumer surplus because those consumers who have the highest willingness to pay would be the only ones to purchase right away. As soon as consumers purchase at a given price, the firm would immediately lower the price and those with a lower willingness to pay would then be targeted.

However, when consumers understand that the firm has incentive to do this, the firm will no longer have the ability to intertemporally price discriminate[5]. Consumers can expect the price to fall to marginal cost and as long as the cost of waiting is small enough, that is what they will do. The firm has little choice but to charge a competitive price right from the beginning. This leaves the firm looking for a way to commit to

[5] The monopolist's incentive to intertemporally price discriminate is known as the 'time-inconsistency problem'.

increasing the consumers' cost of waiting in order to convince consumers, with a high willingness to pay, to purchase right away.

This is where the issue of upgrades comes up. In a market with technological progress, upgrades can increase the consumers' cost of waiting because they can make it less expensive for the consumer to use the most current technology at all times. Therefore, the consumer will be less inclined to delay her purchase, waiting for the technology that is just around the corner.

Fudenberg and Tirole (1998) seek to understand how a monopolist will price successive generations of a durable good. They show when it is optimal for the monopolist to offer an upgrade and identify another time commitment problem caused by upgrades. To do this, their model compares three different information structures that may be available to the firm. The first possibility is that consumers are "anonymous", such as in the market for textbooks. This occurs when former customers have complete anonymity and there exists a second hand market for the old version of the product. Therefore, the monopolist must charge a uniform price for its new version because it cannot price discriminate. Opposite to the anonymous consumer case is the "identified consumers" case, such as in the market for mainframe computers. In this situation, former customers can be tracked and identified. Therefore, the monopolist can segment the markets and perfectly price discriminate, charging a price based on the consumers' willingness to pay. Finally, there is the "semi-anonymous" case, in which the monopolist cannot differentiate between repeat consumers and new consumers without some help from consumers. An example of this case would be the market for computer software.

Getting consumers to identify their 'type' is constrained by two different factors. First, at least one of the two consumer groups must personally gain by stepping forward; this is solved by offering a discounted price. Second, consumers of this group must be able to prove their identity to receive the discounted price. In this case, only past consumers can prove their identity by proving that they still own the old product.

It is found that the semi-anonymous case is not as profitable as the anonymous case for one reason. Because consumers with a high willingness to pay would be the only ones to take advantage of purchasing early, the monopolist will have incentive in the future to raise the price of the upgrade. In comparison, the monopolist in the anonymous case cannot price the upgrade higher than the difference between the value of the new version and the second-hand market price for the old version. If it did, consumers would receive greater value by continuing to use the old version. Therefore, because the monopolist in the semi-anonymous case cannot commit to an upgrade price that is less than the anonymous case, fewer consumers will purchase the upgrade in the semi-anonymous case and profits will be smaller. Waldman (1998) adds to this point by proving that if the monopolist could commit to the future upgrade price early on, the time-inconsistency problem surrounding the upgrade price would be solved.

Lee and Lee (1998) also show that upgrades are also a mixed blessing for the durable goods monopolist. The stated goal of their paper is to analyse the monopolist's choice of economic obsolescence from the perspective of price discrimination. Their results are achieved by assuming that consumers can be divided into two groups: those with a high willingness to pay (H) purchase early and those with a low willingness to pay (L) purchase later. When type L's have a low utility for the new version or type H's have a high incremental utility for the upgrade, the monopolist will have difficulty price discriminating with the upgrade. If the monopolist could completely segregate the two groups, it would charge a higher price for the upgrade than it would for the same product intended for type L's. Unfortunately for the monopolist, this is not the case, and if such a pricing scheme were implemented, type H's would pretend to be type L's to take advantage of the lower price. This leaves the monopolist to explore other options. It can either use a 'pooling price' that represents a single price for both groups that maximises profits or it can offer the old version of the product to type L's. This introduces a new constraint to the monopolist's pricing scheme that ensures it is not cheaper for type H's to delay their initial purchase and buy the old version intended for type L's followed by the upgrade. Ultimately, these constraints on the monopolist weaken its market power. Such limitations may decrease profits so much that the firm may be unwilling to improve its product (Lee and Lee 1998).

Questions about innovation aside, Bensaid and Lesne (1996) show that durable goods markets with network effects reduce the time-inconsistency problem for the monopolist. If the value of the good increases with the installed base of users, then the good will become more valuable over time. This increases the cost for a consumer to delay her purchase because the threat of higher prices in the future is quite real. In fact, it is demonstrated both in Bensaid and Lesne (1996), as well as this paper, that as network effects become stronger, consumers are less likely to delay their purchase.

While these results are important, they are achieved with an entirely different goal in mind. Durable goods monopolist literature asks how the Coase conjecture and the willingness of the monopolist to offer an upgrade will change with the introduction of network effects, information structures, commitment devices, and other features. However, in keeping with durable goods monopolist literature, the assumption is made that there is only one firm. Unfortunately, this makes it impossible to analyse how upgrades are effected by the strategic interaction of multiple firms, which is the focus of this paper. However, intertemporal substitution is a key issue in this paper because the first generation of consumers are faced with the choice of adopting a new technology in its infancy or waiting until it has improved. While technological progress creates economic obsolescence and reduced durability, intertemporal substitution on behalf of early adopters is still possible when network effects and technological progress are low.

2.4 CONCLUSION

Until recently, the concern among economists was that network externalities would give an advantage to the established technology and retard innovation. This is called 'excess inertia'. The intuition behind excess inertia was that no one would wish to leave an established network, even for a vastly superior product, because the value of the network is larger than the incremental benefits offered by the new product. This was re-affirmed by Choi and Thum (1998) by showing a bias toward the established technology. Choi and Thum assume that the *ex post* superior technology does not compete in the first period, giving early adopters a choice between the established technology or waiting until the new technology is released. However, by waiting until the second period, the *ex post* superior technology will not have to compete in the second period against a technology with an installed base. Since it will be able to extract near-monopoly profits in this case, early adopters will purchase in the first period to avoid this exploitation.

However, this result does not hold when the *ex post* superior technology can offer an inferior version in the first period and an upgrade in the second period. This is because, from a welfare perspective, purchasing the first period version of the *ex post* superior technology and upgrading later will be superior to just consuming the *ex post* superior technology in the second period. Additionally, the fact that the *ex post* superior technology has a presence in the first period means that consumers will benefit from price competition. The downside to this, however, is that when the *ex post* superior technology competes in the first period, there are new inefficiencies generated.

If both technologies compete over two periods, the bias can shift to the new technology. This is because the firm backing the *ex post* superior technology can finance penetration (i.e. below cost) pricing in the first period with expected profits from the second period. This bias toward the *ex post* superior technology has significant consequences. For lower rates of technological progress, this bias may improve welfare by increasing the cases of standardisation. However, for high rates of technological progress, this bias will degrade welfare because early adopters are using a vastly inferior product in the first period. Therefore, both Katz and Shapiro (1986) and Thum (1994) prove that new technologies can be adopted too early and too often.

Literature focusing on the adoption behaviour of consumers also arrives at a similar conclusion. For example, Farrell and Saloner (1992) as well as Choi (1996) find that the presence of converters, which are similar to competitive upgrades in that they allow access to the other network, contribute to instances of excess momentum. This conclusion is reached because converters reduce the fear that consumers have of being unable to access the other network, allowing them to purchase a new technology that they otherwise would not. This leads to an excessive use of converters and a fragmented market.

In the following chapter, the excess momentum result is substantially reduced in the competitive upgrade model. This is because when the rate of technology progress is high, the firm will find it more profitable to offer a competitive upgrade instead. Allowing the early adopters to use the better product in first period gives them the opportunity to switch brands in the second period, such that the market can standardise on the *ex post* superior technology.

3 THE MODEL

"In any sane commercial enterprise, once you've paid for a product, you own it. You can take it home and put it on the coffee table and enjoy the rosy glow of ownership for the rest of your life. In the software biz, on the other hand, your purchase price is more like an initiation fee - for a club that plans to charge you annual dues forever." [6]

3.1 INTRODUCTION

In this chapter, a model is developed to explain the behaviour of offering upgrades in the computer software industry. To determine under what conditions competitive upgrades are welfare enhancing, the model is constructed to be similar to those of Katz and Shapiro (1986), Thum (1994), and Choi and Thum (1998). However, in these models, once consumers have chosen a particular brand, they are not permitted to switch to a different brand at a future date. This can be explained by assuming infinite switching costs.

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[6] From "The Software-Upgrade Paradox," *MacWorld* August 1997, p. 206.

Section 3.2 will specify the underlying assumptions of this model. In Section 3.3, these assumptions will be used to determine what will be considered 'socially optimal.' Then, the market outcome is derived in Chapter 4 under the assumption that consumers are locked-in to a brand once they purchase it. This framework is similar to the Katz and Shapiro (1986), Thum (1994), and Choi and Thum (1998) models.

When both technologies are sponsored and consumers are unable to switch brands after the initial purchase, there is a bias toward the *ex post* superior technology. This is the consequence of the *ex post* superior technology's quality advantage in the future, which gives the firm a second-mover advantage. Additionally, if the *ex post* superior technology had an installed base of users by this time, it could fight off competition from the other technology while still extracting surplus from consumers. With this in mind, the firm backing the *ex post* superior technology can use these expected profits to subsidise competition today, even though it holds an inferior technology.

The only difference between Chapter 4 and the Katz and Shapiro (1986) model is that the firm holding the *ex post* superior technology may offer an upgrade to consumers that have already purchased an older version of the same technology. Offering an upgrade allows the firm to sell its improved product to a market segment that did not exist in the Katz and Shapiro model. The upgrade may be quite attractive to these consumers.

especially if the old product cannot fully access the network formed by successive generations of consumers. This will make the *ex post* superior technology more valuable to the early adopters, meaning that a market outcome involving standardisation on the *ex post* superior technology is more likely than in the Katz and Shapiro model.

However, it should be noted that this does not affect the second-mover advantage. These extra profits are being earned from the early adopters in the second period and cannot be used to subsidise competition in the first period. If early adopters pay more in the future, they will require a lower price in the present to purchase the *ex post* superior technology. Since incorrect standardisation and inefficient standardisation are caused by the second-mover advantage, upgrades do not change the incidence of these inefficiencies.

The impact of upgrades on the Katz and Shapiro (1986) model is that they reduce the instances of inefficient fragmentation. Recall that inefficient fragmentation may occur when the market outcome is one where the latter generation of consumers purchases a new technology, failing to follow the choice of the first generation. The inefficiency happens for modest rates of technological progress. At this point, technological progress is high enough that late adopters are attracted to the new technology but it is not high enough such that the first generation adopts the same technology before it has improved.

Furthermore, the rate of technological progress is still low enough that all consumers would be better off if the late adopters chose the old technology that the first generation purchased. Upgrades change this outcome because they allow the first generation of consumers the opportunity to upgrade if they purchase the *ex post* superior technology in the first period. This makes the *ex post* superior technology more valuable and the first generation of consumers are likely to purchase this technology right away. Additionally, if these consumers were to start with the *ex post* superior technology, welfare increases because the next best alternative is fragmentation with the first generation using an inferior technology in the future. Therefore, with both the market and the socially optimal outcome more likely to involve standardisation on the *ex post* superior technology, there will be fewer cases of inefficient fragmentation.

The assumption that consumers cannot switch brands is relaxed for the second half of this chapter. Using the result of Chapter 4 as a benchmark, the model will then be modified in Chapter 5 to allow consumers to switch brands at a future date, thus making competitive upgrades possible. The resulting market equilibrium will depend on the relationship between the benefits of standardising on the *ex post* superior technology, namely the superior stand-alone value and network benefits and the cost of switching between brands. If the firm is to offer a competitive upgrade, its profit will be an increasing function of technological progress and the network benefit because they both make standardisation on the *ex post* superior technology more valuable to consumers. Similarly, the firm's profit will be a decreasing function of the switching cost because if the switching cost is high, consumers will find re-learning a new technology is less attractive. They will be reluctant to purchase a competitive upgrade and the firm will have to offer a lower competitive upgrade price. Therefore, holding all other parameters constant, a smaller switching cost has the effect of making the competitive upgrade more attractive to the first generation. The first generation's increased willingness to pay for the competitive upgrades has two effects on their behaviour. First, if they start with the *ex post* inferior technology, it becomes more attractive to switch to the new technology in the future. Second, if they would otherwise use the *ex post* superior technology from the beginning, it becomes more attractive to start with the *ex post* inferior technology and switch later. Thus, as the switching cost declines, the competitive upgrade outcome becomes more likely because the firm can offer a higher competitive upgrade price while consumer surplus remains unchanged.

Furthermore, the societal welfare of the competitive upgrade outcome increases as the switching cost decreases. All other parameters held constant, as the switching cost declines, the competitive upgrade outcome becomes relatively superior for three reasons. First, compared to the outcome where the market fragments, consumers are better off because the net benefit of switching to the ex post superior technology (i.e. the first generation use a better product plus everyone's network benefit is larger) is increasing. Second, compared to the outcome where consumers standardise on the ex post superior technology from the start, the first generation are better off because the increasing net benefit of using the *ex post* superior technology only once it becomes superior. Third, compared to the outcome where consumers standardise on the ex post inferior technology, all consumers are better off because of the increasing net benefit of using the *ex post* superior technology in the second period.

The market outcome is compared to the socially optimal outcome in Chapter 6. It is found that all three inefficiencies identified by Katz and Shapiro (1986) can be reduced or eliminated by competitive upgrades because when competitive upgrades are the profit maximising strategy for firms, it is also likely that competitive upgrades are socially optimal. Since a competitive upgrade outcome is dependent upon the relative values of the switching cost, the network benefit, and the rate of technological progress, these three parameters play an important role in the conclusions of this chapter. If the switching cost is large compared to the network benefit and the rate of technological progress, then competitive upgrades will rarely be profit maximising or socially optimal and the outcome will not be much different than the case without competitive upgrades. However, if the switching cost is small compared to the network benefit and the rate of technological progress, then competitive upgrades will frequently be profit maximising and socially optimal and the outcome will be efficient.

Each of the three Katz and Shapiro inefficiencies are affected differently as the switching cost declines. As long as the switching cost is finite, inefficient standardisation is always reduced by competitive upgrades. Recall that inefficient standardisation is based on the fact that the *ex post* superior technology can use its second-mover advantage to subsidise today's competition with tomorrow's profits, thus standardising the market. In the absence of competitive upgrades, the inefficiency occurs when the rate of technological progress is high enough to warrant fragmentation. However, when competitive upgrades are incorporated into the model, it becomes optimal to use competitive upgrades in both the market outcome and the socially optimal outcome.

As switching costs decrease even more, it becomes neither socially optimal nor profitable for the *ex post* superior technology to allow the market to fragment. Once the switching cost is small enough relative to the network benefit and the rate of technological progress, then standardisation is superior to fragmentation. A large value of the network benefit favours standardisation in general and a high rate of technological progress favours standardisation on the *ex post* superior technology. Because both inefficient standardisation and inefficient fragmentation are associated with the consumers using the *ex post* inferior technology, competitive upgrades will eliminate these inefficiencies. Additionally, competitive upgrades have an effect on incorrect standardisation. Recall that incorrect standardisation is possible when the rate of technological progress is and standardisation on the *ex post* superior technology is socially optimal. The inefficiency occurs when the *ex post* inferior technology's quality advantage at the start is not large enough to discourage the *ex post* superior technology from subsidising competition. Therefore, for competitive upgrades to be profitable (and socially optimal) for this range of parameter values, the switching cost must be quite small. Consequently, incorrect standardisation is not entirely eliminated unless switching costs are equal to zero.

Competitive upgrades create two new inefficiencies that are actually variants of two of the Katz and Shapiro (1986) inefficiencies. First, for values of the switching cost that are very large compared to the network benefit and the rate of technological progress, competitive upgrades create an inefficiency called *delayed* inefficient standardisation. This occurs because the firm can earn extra profit from using competitive upgrades compared to the next best alternative of fragmentation. However, the firm does not consider that consumers as a whole would be better off if early adopters continued to use the *ex post* inferior technology in the second period rather than going through the trouble of learning a new technology.

Just like the cases of inefficient standardisation and inefficient fragmentation, when it is never profitable or socially optimal for fragmentation to take place, the inefficiency of delayed inefficient standardisation no longer exists. This is again due to the fact that the switching cost is small enough that standardisation is always preferable to fragmentation because the benefits of standardisation, namely the network benefit and the rate of technological advantage, are relatively large. Therefore, the new market outcome using competitive upgrades will be efficient.

At the point where the switching cost is small enough relative to the network benefit and the rate of technological progress to guarantee standardisation, competitive upgrades cause an inefficiency called *delayed* incorrect standardisation. This occurs when the firm uses competitive upgrades to standardise the market on the *ex post* superior technology when the socially optimal outcome dictates standardisation on the *ex post* inferior technology. Once early adopters start using the *ex post* inferior technology, the competitive upgrade allows the firm backing the *ex post* superior technology to capture the entire market in the future when without competitive upgrades, network effects would otherwise make competition unprofitable. Once again, the firm's profit maximising strategy of using competitive upgrades does not consider the fact that that after taking into account the cost of the first generation switching brands, both consumer groups would be comparatively better off by standardising on the other technology.

Similar to the properties of the other inefficiencies, the incidence of delayed incorrect standardisation decreases with the switching cost. As the cost of switching decreases both the socially optimal outcome and the market outcome converge to the use of competitive upgrades. Therefore, as the switching cost tends toward zero, the market becomes perfectly efficient.

3.2 ASSUMPTIONS

In order to provide comparable results, the basic framework of this model will remain almost identical to Katz and Shapiro (1986). It is assumed that there will be two time periods in which there are two generations of consumers and two firms competing. Assumptions regarding the firms will be discussed first.

3.2.1 FIRMS

Two firms, A and B, are assumed to supply the goods "Brand A" and "Brand B" respectively. These two brands are incompatible and can be considered either technologies or standards. Brand A is assumed to be technologically inferior to Brand B in the first period, but becomes superior by the second period. Thus, with δ_{ti} defined as the stand-alone value of brand i at period t, one can state the following: $\delta_{2a} > \delta_b > \delta_{1a}$ where for simplicity, it is assumed that Brand B's quality is fixed such that $\delta_{1b} = \delta_{2b} = \delta_b$. Furthermore, let Δ_t denote B's technology advantage in period t, thus: $\Delta_1 \equiv \delta_b - \delta_{1a} > 0$ and $\Delta_2 \equiv \delta_b - \delta_{2a} < 0$. Finally, marginal costs of production are assumed to be constant and therefore, can be normalised to zero.

3.2.2 CONSUMER PREFERENCES

It is assumed that there are two homogenous generations of consumers with the size of each group equal and normalised to one. The first generation of consumers, called the early adopters, is able to perfectly forecast technological developments and may wish to purchase in both periods. Past the end of the first period, early adopters may switch to a competing technology, but do so at a cost. This assumption reflects the fact that competing computer software applications, while performing the same task, can have a slightly different look and feel. For example, a user upgrading from Word Perfect 6.0 to MS Word 97 must spend some time to learn about the differing terminology, menu structure, and short-cut keys.

In the second period, the second generation of consumers (late adopters) enter the market. At this time, if both groups of consumers use the same compatible standard, both will achieve a network benefit. This assumption is permissible because it is the incremental gain in network benefits that is the most important. Assuming that the early and late adopters can generate a network benefit by themselves will not change the results.

It is assumed that Brand A is fully backward compatible with its own past versions, but the old version is only partially compatible with future versions of the same brand. Therefore, if early adopters use the first version of Brand A and late adopters use the second version of Brand A, not everyone will receive the full network benefit. This assumption is made to reflect the fact that while MS Excel 97 is able to access and save files in MS Excel 5.0 format, MS Excel 5.0 will not be able to recognise the MS Excel 97 format. This may occur because it may be necessary to sacrifice compatibility for the sake of technological progress, but there may also be strategic reasons for the firm to ensure this incompatibility. Examining strategic issues regarding compatibility is not the focus of this paper, but once the model is derived, some general statements can be made about this topic.

Under the above conditions, consumer surplus can be described as below. It is assumed that there is no discounting.

$\gamma n + 2\delta_{1j} - p_{1j}$	for the early adopter who uses the same brand for two periods while late adopters use the same brand
$2\delta_{1j} - p_{1j}$	for the early adopter who uses the same brand for two periods while late adopters use the opposite brand
	(1)

$n + \delta_{1j} + \delta_{2j} - p_{1j} - p_{2j}^{u}$	for the early adopter who purchases an upgrade while late adopters use the same brand
$\delta_{1j} + \delta_{2j} - p_{1j} - p_{2j}^{u}$	for the early adopter who purchases an upgrade while late adopters use the opposite brand
	(2)

$n + \delta_{1j} + \delta_{2j} - \theta - p_{1j} - p_{2j}^{c}$	for the early adopter who purchases a competitive upgrade while late adopters use the same brand
$\delta_{1j} + \delta_{2j} - \theta - p_{1j} - p_{2j}^{c}$	for the early adopter who purchases a competitive upgrade while late adopters use the opposite brand
	(3)

$n + \delta_{2j} - p_{2j}^{n}$	for the late adopter if early adopters use the same brand
$\delta_{2j} - p_{2j}^{n}$	for the late adopter if early adopters use the opposite brand
	(4)

where:

δ_{ij} is the stand-alone, per-period value of the product that is independent of the network externality,

$i = 1,2$ refers to the time period,

$j = a, b$ is the technology or standard,

n is the value of the network benefit (assumed to be linear),

p_{ij} is the price of the product,

$i = 1,2$ refers to the time period,

$j = a, b$ is the technology or standard,

p_{2j}^{z} is the price of the product,

subscript '2' refers to the time period,

$j = a, b$ is the technology or standard,

$z = u, c, n$ differentiates between the prices paid for an upgrade, competitive upgrade, and the new version, respectively,

$0 \leq \gamma \leq 1$ is the degree of compatibility of the first version of Brand A with the second version Brand A; $\gamma = 0$ represents no compatibility and $\gamma = 1$ represents full compatibility,

$\theta > 0$ is the switching cost,

This paper will also follow Katz and Shapiro (1986) by assuming that consumers chose the outcome that is Pareto preferred. This is made to avoid a discussion of multiple equilibria. With network externalities, it is possible that standardisation on technology A even when every consumer prefers technology B, will still be an equilibrium. This is because no individual will want to depart from the group and give up the benefit of being part of the network. Therefore, depending on how consumers co-ordinate themselves, there can be a Nash equilibrium on either the superior technology or the inferior technology. However, this paper will assume that consumers will co-ordinate themselves to form a network around the preferred technology[7].

[7] See Farrell and Saloner (1985) for a detailed discussion of multiple equilibria and network externalities.

3.3 WELFARE

3.3.1 THE SET OF SOCIALLY OPTIMAL OUTCOMES

The socially optimal outcome, in terms of every combination of Δ_1 and Δ_2, will now be defined. If early adopters start with Brand A, they can either upgrade, switch, or continue to use the first version of Brand A. If they start with Brand B, they can either switch or continue to use Brand B. Keeping in mind that late adopters may use either of the two brands in the second period, there are a total of ten possible outcomes. Notation for each scenario will use a two or three letter symbol: the last letter always refers to the technology used by the late adopters and the preceding letters refer to the technology used by the early adopters. Examples of some possible outcomes along with their notation are below:

BB: Both early and late adopters use Brand B.

BA: Early adopters use Brand B for both periods. Late adopters use Brand A.

BCA: Early adopters use Brand B and purchase a competitive upgrade in the second period. Late adopters use Brand A

ABB: Early adopters use Brand A, but switch over to Brand B in the second period. Late adopters also use Brand B.

AUA: Early adopters use Brand A and purchase an upgrade in the second period. Late adopters also use Brand A.

For the purpose of welfare analysis, it is assumed that total surplus will be the welfare measure. The social planner can choose between eight possible patterns of adoption if there are no competitive upgrades[8] or ten possible outcomes if there are competitive upgrades[9]. By comparing all of the possible outcomes, it is clear that the welfare generated by some of these outcomes dominates the welfare generated by others. This means that some outcomes can be immediately disregarded. Using only the feasible scenarios, it will be possible to illustrate the socially optimal outcomes in Figures 1, 2, and 3[10]. The shaded areas represent the parts of each graph that will be derived first.

[8] *AUA*, *AUB*, *AA*, *AB*, *ABA*, *ABB*, *BA*, and *BB*.

[9] *AUA*, *AUB*, *AA*, *AB*, *ABA*, *ABB*, *BCA*, *BCB*, *BA*, and *BB*.

[10] Note that due to space considerations, the figures presented in this paper are not to scale.

Figure 1: Socially optimal outcome with no competitive upgrades.

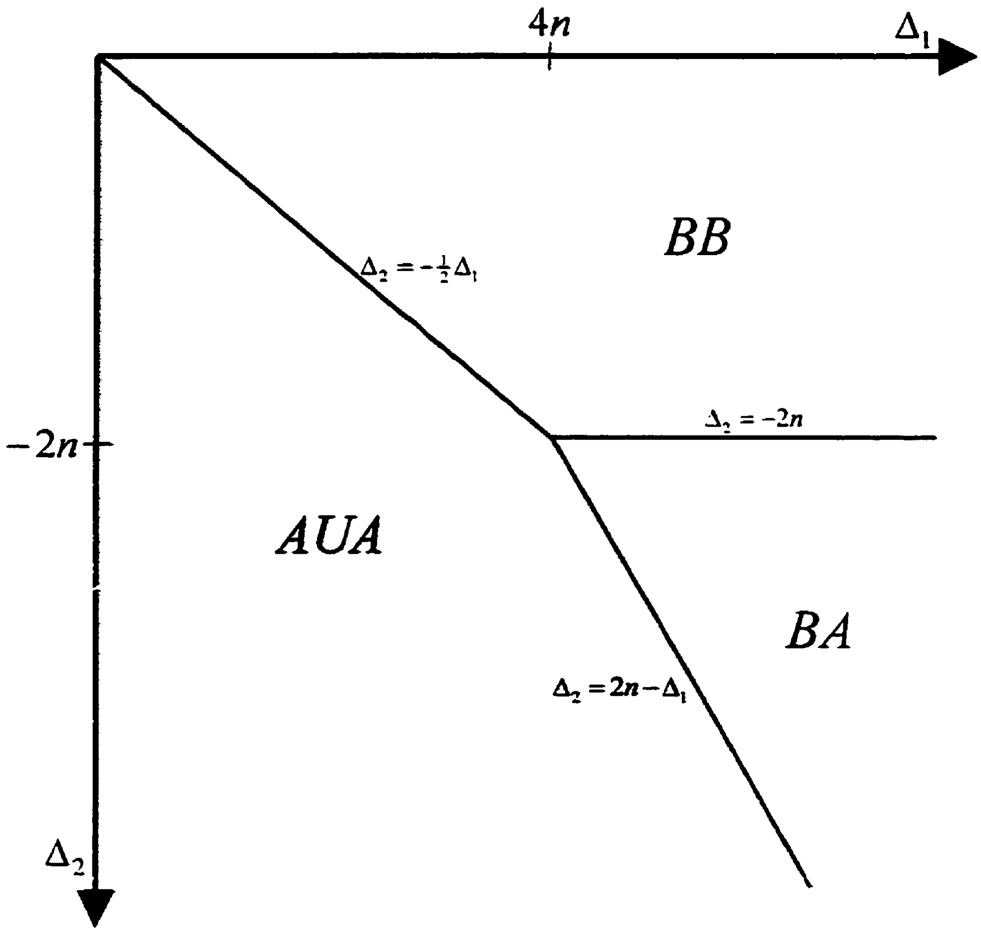

Figure 2: Socially optimal outcome with competitive upgrades and large switching cost ($\theta > 4n$).

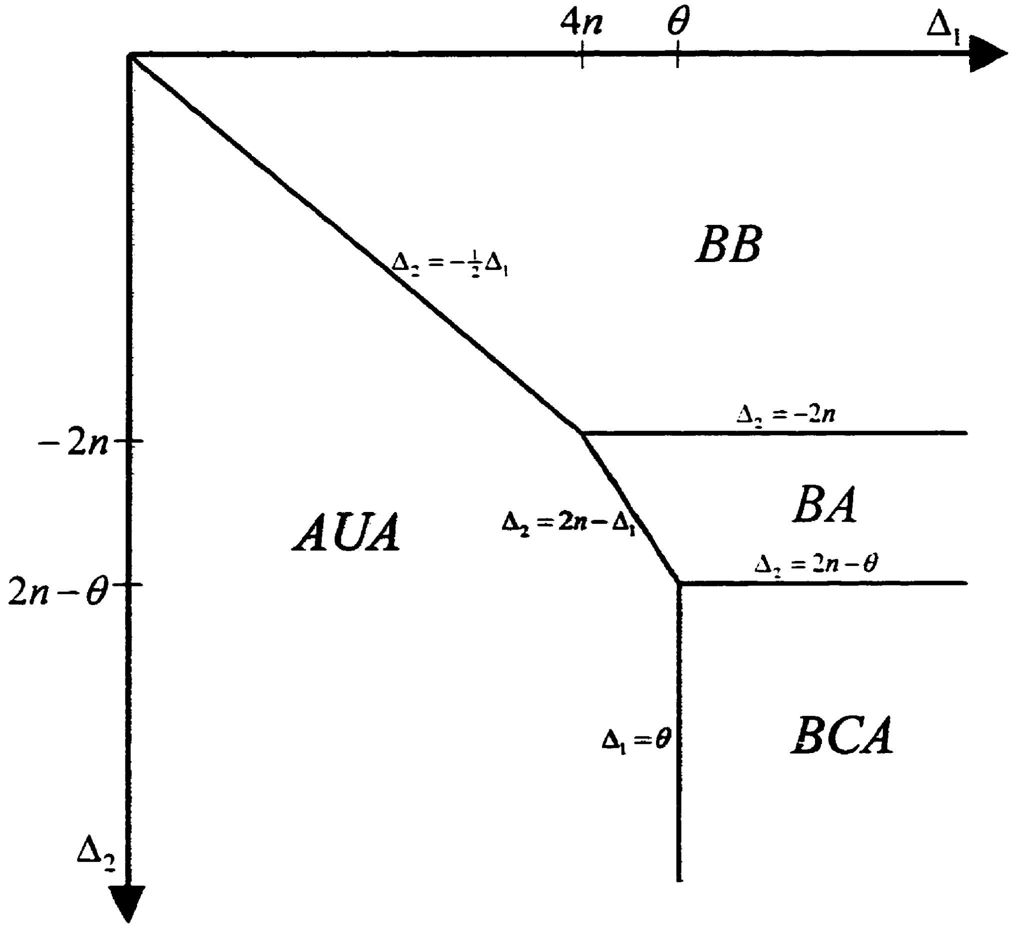

Figure 3: Socially optimal outcome with competitive upgrades and small switching costs ($\theta \leq 4n$).

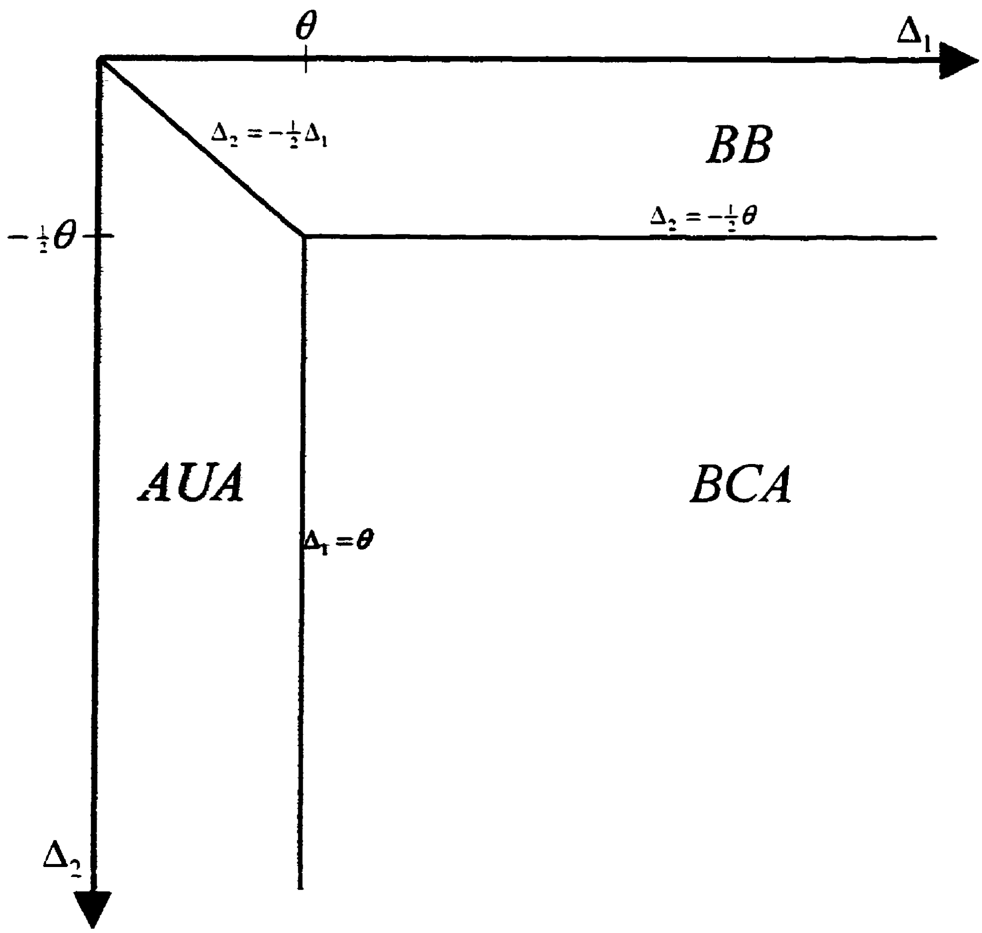

Figure 1 represents the set of socially optimal outcomes when there are no competitive upgrades. The discussion of this diagram is as follows. First, $|\Delta_2| = \frac{1}{2}\Delta_1$ represents the boundary where W_{AUA} is equal to W_{BB}. Outcome AUA means that early adopters will be using the inferior version of Brand A in the first period. This is not the best technology available in the first period because Brand B is better. In comparison, outcome BB means that both early and late adopters will be using Brand B in the second period when Brand A is better. If the social planner were to move from outcome AUA to outcome BB, early adopters would gain Δ_1 from using a better product in the first period, but both early and late adopters would give up $|\Delta_2|$ because they now use an inferior product in the second period[11]. Therefore, for W_{AUA} to be considered equivalent to W_{BB}, Brand B's first period quality advantage must be exactly twice as great as Brand A's second period quality advantage. If Δ_1 is less than $2 \cdot |\Delta_2|$, then W_{AUA} is superior because the gains of moving to outcome BB do not justify the costs of moving away from AUA.

Next, $|\Delta_2| = 2n$ represents the boundary where W_{BB} is equal to W_{BA}. Outcome BB means that both early and late adopters do not use the best product available in the second period. In comparison, outcome BA means that only the early adopters do not use the best product available in the second period, but there is no longer standardisation. If

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[11] There is standardisation in either case, so network benefits are irrelevant.

the social planner were to move from outcome BB to outcome BA, late adopters would gain $|\Delta_2|$ from using a better product in the second period, but both groups would forfeit the network benefit. Therefore, for W_{BB} to be considered equivalent to W_{BA}, the network benefit must be exactly twice as great as Brand A's second period quality advantage. If $|\Delta_2|$ is less than $2n$, then W_{BB} is superior because the gains of moving to outcome BA do not justify the costs of moving away from BB.

Finally, $|\Delta_2| = \Delta_1 - 2n$ represents the boundary where W_{AUA} is equal to W_{BA}. Outcome AUA means that early adopters will be using the inferior version of Brand A in the first period. In comparison, outcome BA means that the early adopters can use the best product available in the first period. However, this product will not be the best available in the second period and since late adopters use a different brand, both groups will miss out on the network benefit because there is no longer standardisation. If the social planner were to move from outcome AUA to outcome BB, early adopters would gain Δ_1 from using a better product in the first period, but those same early adopters would not be using the best product available in the second period. Additionally, both groups would forfeit the network benefit. Therefore, for W_{AUA} to be considered equivalent to W_{BA}, Brand B's first period quality advantage must be equal to twice the network benefit plus Brand A's second period quality advantage. If Δ_1 is less than

$2n+|\Delta_2|$, then W_{AUA} is superior because the gains of moving to outcome BA do not justify the costs of moving away from AUA.

Figure 2 represents the set of socially optimal outcomes with competitive upgrades, but large switching costs. For the most part, this is identical to Figure 1 with the addition of region BCA. This area exist only for large values of $|\Delta_2|$ because the rate of technological progress must be high enough to justify the cost of switching brands. First, $|\Delta_2| = \theta - 2n$ represents the boundary where W_{BA} is equal to W_{BCA}. Outcome BA means that early adopters do not use the best product available in the second period. In comparison, outcome BCA means that early adopters use the best product available in both the first and second period. Additionally, standardisation on Brand A means that both groups now receive the network benefit. However, to do this, early adopters will incur a switching cost when they learn a different technology. If the social planner were to move from outcome BA to outcome BCA, early adopters would gain $|\Delta_2|$ from using a better product in the second period plus both groups would gain the network benefit. The cost of this move is that early adopters incur a cost equal to θ. Therefore, for W_{BA} to be considered equivalent to W_{BCA}, the switching cost must be equal to Brand A's second period quality advantage plus twice the network benefit. If $2n+|\Delta_2|$ is less than θ, then W_{BA} is superior because the gains of moving to outcome BCA do not justify the costs of moving away from BA.

The second line, $\Delta_1 = \theta$, marks the boundary where W_{AUA} is equal to W_{BCA}. Outcome AUA means that early adopters will be using the inferior version of Brand A in the first period. In comparison, outcome BCA means that early adopters use the best product available in both the first and second period. Additionally, standardisation on Brand A means that both groups now receive the network benefit. However, to do this, early adopters must incur a switching cost when they learn a different technology. If the social planner were to move from outcome AUA to outcome BCA, early adopters would gain Δ_1 from using a better product in the first period. However, they would give up θ from learning a new technology[12]. Therefore, for W_{AUA} to be considered equivalent to W_{BCA}, Brand B's first period quality advantage must be equal to the switching cost. If Δ_1 is less than θ, then W_{AUA} is superior because the gains of moving to outcome BCA do not justify the costs of moving away from AUA.

Figure 3 represents the set of socially optimal outcomes with competitive upgrades and small switching costs. Of note is that region BA does not appear in Figure 3. Region BA does not appear for two reasons. First, if W_{BB} dominates W_{BA} it is because the benefits to late adopters of using the improved version of Brand A are outweighed by the loss of the network benefit to all consumers. Second, if W_{BCA} dominates W_{BA} it is

[12] Remember that there is standardisation in either case, so network effects are irrelevant.

because the early adopters now benefit by using the new version of Brand A and all consumers benefit by forming a network. This is measured against the switching cost, which early adopters must incur to switch to Brand A. With these two conditions put together, if the switching cost is less than $4n$, both BCA and BB are superior to BA.

While the boundary between W_{AUA} and W_{BB} remains the same as in the first two diagrams, the boundaries involving W_{BCA} change. First, $|\Delta_2| = \frac{1}{2}\theta$ represents the boundary where W_{BB} is equal to W_{BCA}. Outcome BB means that both early and late adopters do not use the best product available in the second period. In comparison, outcome BCA means that both early and late adopters use the best product available in the second period without early adopters having to give up using the best product available in the first period. However, to do this, early adopters must incur a switching cost when they move to a different technology. If the social planner were to move from outcome BB to outcome BCA, early and late adopters would each gain $|\Delta_2|$ from using a better product in the second period, but early adopters would incur a cost equal to θ. Therefore, for W_{BB} to be considered equivalent to W_{BCA}, the switching cost must be equal to twice Brand A's second period quality advantage. If $2 \cdot |\Delta_2|$ is less than θ, then W_{BB} is superior because the gains of moving to outcome BCA do not justify the costs of moving away from BB.

Finally, $\Delta_1 = \theta$, marks the boundary where W_{AUA} is equal to W_{BCA}. Outcome AUA means that early adopters will be using the inferior version of Brand A in the first period. This is not the best technology available in the first period because Brand B is better. In comparison, outcome BCA means that early adopters use the best product available in both the first and second period. However, to do this, early adopters must incur a switching cost when they learn a different technology. If the social planner were to move from outcome AUA to outcome BCA, early adopters would gain Δ_1 from using a better product in the first period. However, they would give up θ from learning a new technology. Therefore, for W_{AUA} to be considered equivalent to W_{BCA}, Brand B's first period quality advantage must be equal to the switching cost. If Δ_1 is less than θ, then W_{AUA} is superior because the gains of moving to outcome BCA do not justify the costs of moving away from AUA.

To begin the proofs of Figures 1 through 3, it is first necessary to create a summary of all of the possible outcomes and the social welfare associated with them. They appear below in Table 1.

Table 1: Welfare values for all possible patterns of adoption.

- $W_{AUA} = 2n + \delta_{1a} + 2\delta_{2a}$
- $W_{AUB} = \delta_{1a} + \delta_{2a} + \delta_{b}$
- $W_{AA} = n + \gamma n + 2\delta_{1a} + \delta_{2a}$
- $W_{AB} = 2\delta_{1a} + \delta_{b}$
- $W_{ABA} = \delta_{1a} + \delta_{b} + \delta_{2a} - \theta$
- $W_{ABB} = 2n + \delta_{1a} + 2\delta_{b} - \theta$
- $W_{BCA} = 2n + \delta_{b} + 2\delta_{2a} - \theta$
- $W_{BCB} = \delta_{2a} + 2\delta_{b} - \theta$
- $W_{BA} = 2\delta_{b} + \delta_{2a}$
- $W_{BB} = 2n + 3\delta_{b}$

Some patterns of adoption are dominated by others and can be immediately eliminated. For example, W_{AA} is strictly greater than W_{AB} because $n(1+\gamma)+\delta_{2a}$ is greater than δ_b. This makes intuitive sense because using the worst technology in both periods should produce a lower level of welfare than using the worst technology in only the first period. Furthermore, by similar reasoning W_{AUA} dominates W_{AUB}, W_{BCA} dominates W_{BCB}, W_{AUA} dominates W_{ABA}, W_{BB} dominates W_{ABB}, and W_{AUA} dominates W_{AA}.

This leaves W_{AUA}, W_{BB}, W_{BA}, and W_{BCA}[13]. Whichever outcome dominates will depend on the relative magnitude of the network benefit, the cost of switching, and the

[13] Remember that W_{BCA} is only relevant in the case of competitive upgrades

improvement in technology A over the two periods (as represented by Δ_1 and Δ_2). Between Figures 2 and 3, the size of the switching cost (θ) compared to the network benefit ($4n$) will influence which diagram represents the socially optimal outcome. This is proven in Lemma 1.

Lemma 1: For the case of competitive upgrades, if the cost of switching is no more than four times the network benefit, the socially optimal pattern of adoption should always be one of standardisation. The outcome involving each consumer group using different technologies, BA, is never optimal.

Proof: For the region of BA in Figure 2 to be considered socially optimal, it must generate higher surplus than the outcomes BB and BCA. In other words, if W_{BA} is never greater than W_{BB} and W_{BCA}, the region of BA is 'squeezed' out of Figure 2 because it can never be socially optimal. Using the values for W_{BA}, W_{BB}, and W_{BCA} found in Table 1, W_{BB} dominates W_{BA} as long as Δ_2 is greater than $-2n$ and W_{BCA} dominates W_{BA} as long as Δ_2 is less than $2n-\theta$. Therefore, both W_{BB} and W_{BCA} dominate W_{BA} when Δ_2 is between $-2n$ and $2n-\theta$, which can be written as the condition $-2n \le \Delta_2 \le 2n-\theta$. However, the condition $-2n \le \Delta_2 \le 2n-\theta$ cannot be met if $-2n$ is greater than $2n-\theta$, which is true if θ is greater than $4n$. Therefore, provided that the condition $\theta \le 4n$ is met, W_{BA} is dominated by both W_{BB} and W_{BCA}. This means that the only possible socially optimal outcomes are AUA, BB, and BCA. Q.E.D.

Lemma 1 defines when the region of BCA dominates BA for all parameter values. This is shown in Figure 3. Next, each region within Figures 1 through 3 will be explained. First, the welfare of both groups using Brand A is compared to both groups using Brand B. This is the dividing line between AUA and BB in Figures 1 through 3. To help in the construction of each diagram, the shaded area in all three figures represents the case where W_{AUA} is greater than W_{BB}. This boundary is defined in Lemma 2.

Lemma 2: The equation $\Delta_2 = -\frac{1}{2}\Delta_1$ represents the combinations of Δ_1 and Δ_2 that make W_{AUA} equivalent to W_{BB}. For values of Δ_2 greater than $-\frac{1}{2}\Delta_1$, W_{BB} is greater than W_{AUA} and for values of Δ_2 less than $-\frac{1}{2}\Delta_1$, W_{AUA} is greater than W_{BB}.

Proof: Based on the values in Table 1, the difference between W_{BB} and W_{AUA} is:

$$W_{BB} - W_{AUA} = \Delta_1 + 2\Delta_2. \tag{5}$$

Therefore, if Equation (5) is equal to zero, there is no difference between W_{BB} and W_{AUA}. For this to happen, Δ_2 must be equal to $-\frac{1}{2}\Delta_1$. For values of Δ_2 greater than $-\frac{1}{2}\Delta_1$ (the non-shaded area of Figures 1 through 3), W_{BB} is greater than W_{AUA} and for values of Δ_2

is less than $-\frac{1}{2}\Delta_1$ (the shaded area of Figures 1 through 3), W_{AUA} is greater than W_{BB}. Q.E.D.

Now Figures 1 through 3 can be split into two parts:

(1) When Δ_2 is greater than $-\frac{1}{2}\Delta_1$ (the non-shaded area of Figures 1 through 3) and,

(2) When Δ_2 is less than $-\frac{1}{2}\Delta_1$ (the shaded area of Figures 1 through 3).

When W_{AUA} is greater than W_{BB}, Lemmas 3 to 5 will compare the outcomes of AUA, BA, and BCA. When W_{BB} is greater than W_{AUA}, Lemmas 6 to 8 will compare the outcomes BB, BA, and BCA.

Lemma 3: Given that W_{AUA} is greater than W_{BB}, W_{AUA} is equivalent to W_{BA} when Δ_2 is equal to $2n-\Delta_1$. If Δ_2 is less than $2n-\Delta_1$, W_{AUA} is greater than W_{BA}. If Δ_2 is greater than $2n-\Delta_1$, W_{BA} is greater than W_{AUA}.

Proof: Using Table 1, the difference between W_{AUA} and W_{BA} is:

$$W_{AUA} - W_{BA} = 2n - \Delta_1 - \Delta_2. \quad (6)$$

If this difference is equal to zero, Equation (6) becomes $\Delta_2 = 2n - \Delta_1$. If Equation (6) is positive then Δ_2 is less than $2n-\Delta_1$ and W_{AUA} is greater than W_{BA}. If Equation (6) is negative then Δ_2 is greater than $2n-\Delta_1$ and W_{BA} is greater than W_{AUA}. Q.E.D.

Within the shaded area of Figures 1 through 3, if Δ_2 is less than $2n - \Delta_1$, it is established that W_{AUA} is greater than both W_{BB} and W_{BA}. Lemma 4 will assume this is true and will compare W_{AUA} with W_{BCA}. However, if within the shaded area of Figures 1 through 3, Δ_2 is greater than $2n - \Delta_1$ then W_{BA} is greater than both W_{BB} and W_{AUA}. Lemma 5 will assume Δ_2 is greater than $2n - \Delta_1$ and compare W_{BA} with W_{BCA}.

Lemma 4: Given that W_{AUA} is greater than both W_{BB} and W_{BA}, W_{AUA} is equivalent to W_{BCA} when Δ_1 is equal to θ. If Δ_1 is less than θ, W_{AUA} is greater than W_{BCA}. If Δ_1 is greater than θ, W_{AUA} is greater than W_{BCA}.

Proof: Using Table 1, the difference between W_{AUA} and W_{BCA} is:

$$W_{AUA} - W_{BCA} = \theta - \Delta_1. \quad (7)$$

Therefore, if Equation (7) is equal to zero, Δ_1 is equal to θ. For values of Δ_1 greater than θ, W_{BCA} is greater than W_{AUA} and for values of Δ_2 less than θ, W_{AUA} is greater than W_{BCA}. Q.E.D.

Lemma 5: Given that W_{BA} is greater than W_{BB} and W_{AUA}, W_{BA} is equivalent to W_{BCA} when Δ_2 is equal to $2n-\theta$. If Δ_2 is less than $2n-\theta$, W_{BCA} is greater than W_{BA}. If Δ_2 is greater than $2n-\theta$, W_{BA} is greater than W_{BCA}.

Proof: Using Table 1, the difference between W_{BA} and W_{BCA} is:

$$W_{BA} - W_{BCA} = \Delta_2 - 2n + \theta . \tag{8}$$

Thus, if Equation (8) is equal to zero, Δ_2 is equal to $2n-\theta$. For values of Δ_2 greater than $2n-\theta$, W_{BA} is greater than W_{BCA} and for values of Δ_2 less than $2n-\theta$, W_{BCA} is greater than W_{BA}. Q.E.D.

Now suppose Δ_2 is greater than $-\frac{1}{2}\Delta_1$, which is represented by the non-shaded area of Figures 1 through 3. Under this condition, W_{BB} is greater than W_{AUA}. Now, outcome BB must be compared to BA and BCA in Lemmas 6 through 8.

Lemma 6: Given that W_{BB} is greater than W_{AUA}, W_{BB} is equivalent to W_{BA} when Δ_2 is equal to $-2n$. If Δ_2 is less than $-2n$, W_{BA} is greater than W_{BB}. If Δ_2 is greater than $-2n$, W_{BB} is greater than W_{BA}.

Proof: Using Table 1, the difference between W_{BB} and W_{BA} is:

$$W_{BB} - W_{BA} = 2n + \Delta_2 . \quad (9)$$

Therefore, if Equation (9) is equal to zero, Δ_2 is equal to $-2n$. For values of Δ_2 greater than $-2n$, W_{BB} is greater than W_{BA} and for values of Δ_2 less than $-2n$, W_{BA} is greater than W_{BB}. Q.E.D.

Lemma 7: Given that W_{BA} is greater than W_{ACA} and W_{BB}, W_{BA} is equivalent to W_{BCA} when Δ_2 is equal to $2n-\theta$. If Δ_2 is less than $2n-\theta$, W_{BCA} is greater than W_{BA}. If Δ_2 is greater than $2n-\theta$, W_{BA} is greater than W_{BCA}.

Proof: See Lemma 5.

Lemma 8: Given that W_{BB} is greater than W_{ACA} and W_{BA}, W_{BB} is equivalent to W_{BCA} when Δ_2 is equal to $-\frac{1}{2}\theta$. If Δ_2 is less than $-\frac{1}{2}\theta$, W_{BCA} is greater than W_{BB}. If Δ_2 is greater than $-\frac{1}{2}\theta$, W_{BB} is greater than W_{BCA}.

Proof: Using Table 1, the difference between W_{BB} and W_{BCA} is:

$$W_{BB} - W_{BCA} = 2\Delta_2 + \theta . \quad (10)$$

Therefore, if Equation (10) is equal to zero, Δ_2 is equal to $-\frac{1}{2}\theta$. For values of Δ_2 greater than $-\frac{1}{2}\theta$, W_{BB} is greater than W_{BCA} and for values of Δ_2 less than $-\frac{1}{2}\theta$, W_{BCA} is greater than W_{BB}. Q.E.D.

Using Table 2, there now exists enough information to construct Figures 1 through 3.

Table 2: Summary of Lemmas 1 through 8.

For $\theta \le 4n$		
Optimal outcome	**Boundaries**	**Derived from Lemma(s)**
AUA	Below $\Delta_2 = -\frac{1}{2}\Delta_1$ and left of $\Delta_1 = \theta$	2 and 4
BB	Above both $\Delta_2 = -\frac{1}{2}\Delta_1$ and $\Delta_2 = -\frac{1}{2}\theta$	2 and 8
BCA	Below $\Delta_2 = -\frac{1}{2}\theta$ and right of $\Delta_1 = \theta$	8 and 4
For $\theta > 4n$		
Optimal outcome	**Boundaries**	**Derived from Lemma(s)**
AUA	Below both $\Delta_2 = -\frac{1}{2}\Delta_1$ and $\Delta_2 = 2n - \Delta_1$, but left of $\Delta_1 = \theta$	2, 3, and 4
BB	Above both $\Delta_2 = -\frac{1}{2}\Delta_1$ and $\Delta_2 = -2n$	2 and 6
BA	Above both $\Delta_2 = 2n - \Delta_1$ and $\Delta_2 = 2n - \theta$, but below $\Delta_2 = -2n$	3, 5/7, and 6
BCA	Below $\Delta_2 = 2n - \theta$, and right of $\Delta_1 = \theta$	5/7 and 4

For Figure 1, where there are no competitive upgrades, outcome BCA is irrelevant. Therefore, so are Lemmas 1, 4, 5, 7, and 8. Figure 3 is a case were competitive upgrades exist, but W_{BA} is dominated by both W_{BB} and W_{BCA}, so Lemmas 3, 5, 6, and 7 are inapplicable. For Figure 2, outcomes AUA, BB, BA, and BCA are all possible and

Lemmas 1 through 8 will all apply. Therefore, as Figures 1 and 3 are merely subsets of Figure 2, Table 2 shows the mathematical foundation for all three figures.

4 MARKET EQUILIBRIUM: CONSUMERS ARE LOCKED-IN

For the purposes of creating a benchmark against which to show the effects of competitive upgrades, the model will first be developed under the assumption that early adopters may not switch brands after the first period (i.e. switching costs are infinite). Consequently, competition between the two firms for early adopters occurs only in the first period. Under this situation, the following market outcome, illustrated in Figure 4 occurs.

Figure 4: Market equilibrium; with upgrades, but without competitive upgrades.

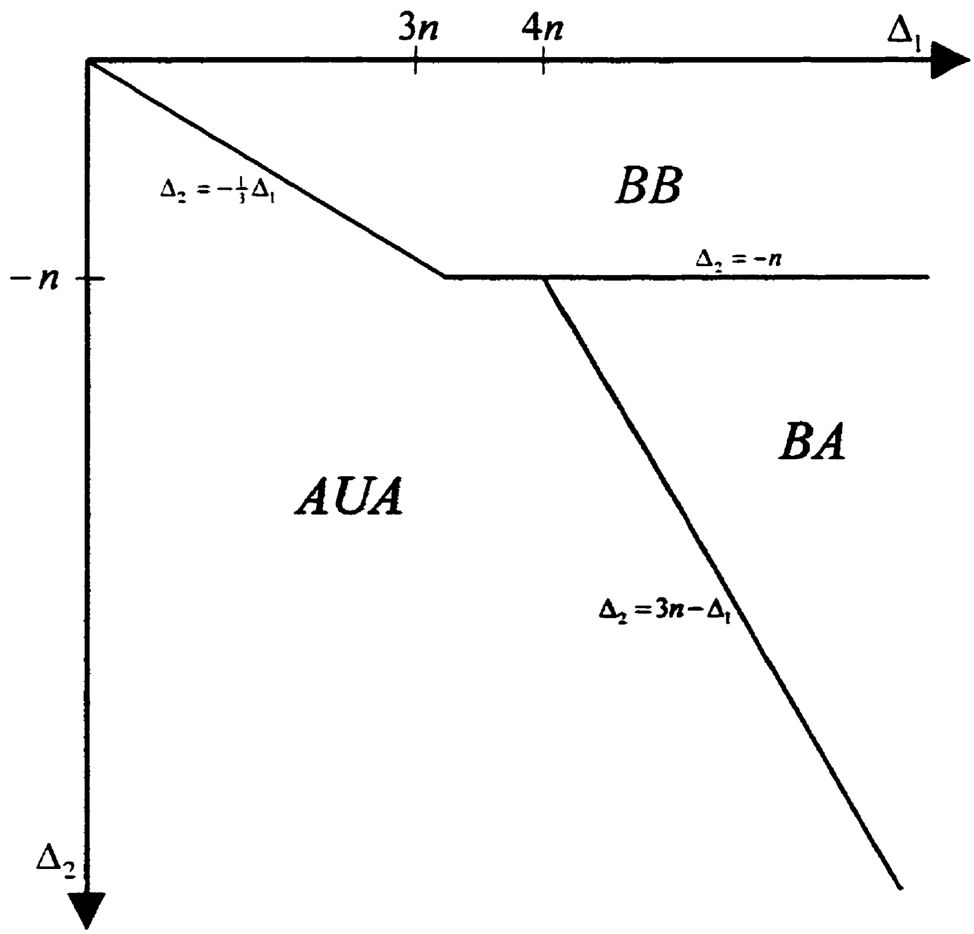

Figure 4 represents the market outcome for the case of no competitive upgrades. It is very similar to the market outcome in the Katz and Shapiro (1986) model with some exceptions. First, the boundary $|\Delta_2| = n$ marks the point where Firm A's second period quality advantage is equal to the network benefit. Once $|\Delta_2|$ is larger than n, it is possible for the market to fragment if early adopters use Brand B in the first period. At this point, late adopters will have such a high willingness to pay for the superior quality of Brand A, Firm A can always profitably sell to the late adopters even if Brand A's value is degraded by a lack of a network benefit. Nevertheless, by choosing Brand A, late adopters will be better off because the quality improvement over Brand B outweighs the network benefit associated with using the same brand as early adopters.

When the market always standardises, Brand A's quality advantage in the second period is small compared to the network benefit. Thus, all consumers will place a priority on the network in the second period, and once consumers standardise on Brand A, Firm A can extract surplus equal to the second period quality advantage from each of the consumer groups. The boundary $|\Delta_2| = \frac{1}{3}\Delta_1$ is where Firm A earns zero profits and is indifferent between winning the competition for consumers (outcome AUA) or conceding the market to Firm B (outcome BB). This non-symmetrical boundary is biased toward Firm A because its quality advantage in the second period allows it to extract more profits than what Firm B could. Therefore, in the first period, Firm A can lower its price to compensate early adopters for not only choosing an inferior product, but the network benefit that they confer on late adopters in the second period. This means that the second period quality advantage of Brand A can be up to three times worse than Brand B's first period quality advantage and Firm A can still earn a positive profit.

When it is possible for the market to fragment, Firm A can always profitably sell to the late adopters. Thus, the choice for early adopters will be to decide whether standardising on Brand A in the second period justifies using the inferior version of Brand A in the first period. If they do choose Brand A, Firm A can extract n from each of the consumer groups in addition to a gain of n from *not* selling to only the late adopters[14]. Consequently, the boundary $|\Delta_2| = \Delta_1 - 3n$ is where Firm A earns zero profits and is indifferent between winning the competition for early adopters (outcome AUA) or just selling to the late adopters (outcome BA). This means that the network benefit can be up to three times worse than Brand A's second period quality advantage before Firm A's profit maximising strategy becomes BA.

To derive Figure 4, it is first necessary to identify when it is possible for the market to fragment. This plays an important role in the market outcome because Firm A's

[14] Remember that Firm A's profits in the event of just selling to the late adopters is decreasing in n because as the network benefit increases, Firm A has to charge a lower price to late adopters to keep them from joining early adopters in a network of Brand B.

ability to profitably sell to just the late adopters in the second period will change its actions in the first period.

Proposition 1: If $|\Delta_2| > n$, then the quality differential in the second period is so large that Firm A can always sell to the late adopters and always make a profit. This means it is possible for the market to fragment. Otherwise, if $|\Delta_2| \leq n$, then the network benefit is so large that Firm A cannot profitably sell to the late adopters if early adopters use Brand B. In this case, the market will always standardise.

Proof: Suppose that the early adopters use Brand A and the firms must now compete for the late adopters[15]. When offering a price for Brand A, the maximum that Firm A can charge late adopters would satisfy the equation $n + \delta_{2a} - p_{2a}^n = \delta_b - p_{2b}$, where the left hand side is the net benefit of choosing Brand A and the right hand side is the net benefit of choosing Brand B. However, early adopters use Brand A and this is the last period so Firm B will not price below zero. Thus, Firm A can charge a price that would satisfy the equation $n + \delta_{2a} - p_{2a}^n = \delta_b$ to keep the consumer indifferent between the two brands. Therefore, the maximum price that Firm A can charge is

$$p_{2a}^n = n - \Delta_2 > 0. \tag{11}$$

[15] It is irrelevant which version Brand A the early adopters use. It is assumed that the new version of Brand A will be fully compatible with all prior versions.

Under the assumption of zero marginal costs, this price is also equal to profits[16]. Also note that the profit in (11), is positive because Δ_2 is negative.

Now suppose that early adopters use Brand B. In this case, the maximum that Firm A can charge late adopters would satisfy the equation $\delta_{2a} - p_{2a}^n = n + \delta_b - p_{2b}$. Firm B will still not be willing to price below zero, so the maximum price that Firm A can charge is

$$p_{2a}^n = -n - \Delta_2 . \tag{12}$$

Whether or not the profits in (12) are positive or negative is uncertain; all that can be said is that p_{2a}^n in Equation (11) is greater than p_{2a}^n in Equation (12). However, if $|\Delta_2| > n$, then profit in (12) is strictly positive and Firm A will always be willing to charge a price low enough such that late adopters will buy Brand A no matter what brand the early adopters use. Thus, it is possible for the market to fragment. If $|\Delta_2|$ is not greater than n, then profit in (12) is non-positive. In this case, given that early adopters use Brand B, Firm A cannot profitably sell to the late adopters, leaving Firm B the opportunity to sell to both groups. Thus, the market will always standardise. Q.E.D.

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[16] Recall that the number of consumers is normalised to one.

With Proposition 1 in mind, the derivation of Figure 4 will be solved in two halves. Section 4.1 will assume $|\Delta_2|$ is greater than n, meaning the rate of technological progress is large relative to the network benefit and it is possible for the market to fragment. This is represented by the shaded area in Figure 4. On the other hand, section 4.2 will assume $|\Delta_2|$ is less than n, meaning the rate of technological progress is small relative to the network benefit and the market will always standardise. This is represented by the non-shaded area in Figure 4.

4.1 CASE ONE: IT IS POSSIBLE FOR THE MARKET TO FRAGMENT

Within this Section, the shaded area of Figure 4 is discussed. This is where Firm A's quality advantage is considered "large" due to a high rate of technological progress. It will be shown that under these conditions, the possible market outcomes will be BA or AUA.

The fact that late adopters will always use Brand A when Firm A's quality advantage is large compared to the network benefit comes from Proposition 1. Knowledge that it can always profitably sell to the late adopters puts Firm A in the position of being guaranteed positive profits. All that remains is to decide what is most profitable: selling to just the late adopters (as Proposition 1 found was possible), or offering a first period price low enough such that early adopters also buy. Proposition 1 found that late adopters will pay more for Brand A if early adopters use the same technology and it is possible that Firm A will be able to sell an upgrade. To calculate the total second period payoff from selling to the early adopters in the first period, one must also determine what early adopters will be willing to pay for an upgrade.

Lemma 9: Given that it is possible for the market to fragment (as defined in Proposition 1) and that the early adopters start by using Brand A, they will purchase an upgrade at the price of:

$$p_{2a}^{u} = \begin{cases} (1-\gamma)n + \delta_{2a} - \delta_{1a} & \text{if } \Delta_1 < \gamma n \\ n - \Delta_2 & \text{otherwise} \end{cases}$$

Proof: Once early adopters are locked-in to Brand A, Firm A will be able to make an upgrade offer without competition from Firm B. This leaves early adopters with the choice between using the old version of A for another period or purchasing the upgrade. If they continue to use the old version of Brand A, they will incur no more costs in the second period, but will only be able to access a fraction of the full network benefit (γn). If they pay p_{2a}^{u} for the upgrade, they will get a better product and be able to receive the full network benefit. Thus, the price that makes the early adopters indifferent between buying the upgrade and doing nothing satisfies the equation $n + \delta_{2a} - p_{2a}^{u} = \gamma n + \delta_{1a}$. Solved for p_{2a}^{u}, the maximum that Firm A can charge for an upgrade is $(1-\gamma)n + \delta_{2a} - \delta_{1a}$. Note that this price is strictly positive, meaning that Firm A will increase its profit over just selling to the late adopters. However, this upgrade price brings up the issue of arbitrage[17]. The upgrade price is less than the regular price only if

[17] There is an upper limit to the upgrade price. Only if the upgrade price were less than the new product price would early adopters identify themselves by proving they own the original version. Otherwise, early adopters have no motivation to differentiate themselves from the late adopters because to do so would only ensure that they pay more. For more on this, see Fudenberg and Tirole (1998).

$(1-\gamma)n+\delta_{2a}-\delta_{1a}$ is less than $n-\Delta_2$ (from Equation (11)), which after cancelling like terms, can be reduced down to the form $\Delta_1 < \gamma n$. If Δ_1 is greater than γn, then early adopters will practice arbitrage by purchasing the new product instead. Q.E.D.

Lemma 9 shows that if early adopters purchase Brand A in the first period, Firm A will be able to offer an upgrade that early adopters will be willing to buy. In addition to the fact that they purchase the upgrade, in some cases they will be willing to pay more than the late adopters if Δ_1 is greater than γn. This result is identical to Thum (1994). Upgrades become irrelevant when early adopters value the new version more than late adopters do, so the firm cannot price discriminate. Early adopters find the new version more valuable for two possible reasons. If Δ_1 is large (the left-hand side of the arbitrage condition), the product early adopters use in the first period is of low quality relative to both δ_b and δ_{2a}. In this case, upgrading to the new version of Brand A would represent a significant increase in stand-alone quality. By comparison, the late adopters are not faced with such an extreme choice because their next best alternative is Brand B. If γn is small (the right-hand side of the arbitrage constraint), the original version of Brand A is of low network value. In this case, upgrading to the new version of Brand A would represent a significant increase in network benefits. Late adopters do not face this problem at all because the new version of Brand A is backward compatible with the old version.

With a full understanding of the second period profits available to Firm A, should early adopters use Brand A in the first period, Firm A can evaluate the costs of competing in the first period with an inferior product. Remember that these second period profits give Firm A an advantage over Firm B in the first period: Firm B cannot expect to earn any profits in the second period, even if it manages to sell to the early adopters. Lemmas 10, 11, and 12 will outline Firm A's decision between AUA and BA by first calculating the cost of competing in the first period with an inferior product, then calculating the total net profits of AUA. This can then be compared to the profits of just selling to the late adopters, as found in Proposition 1.

Lemma 10: The total price that early adopters pay for both versions of Brand A will be:

$$p_{2a}^{u} + p_{2a}^{n} = n - \Delta_1 - \Delta_2$$

Proof: Given that early adopters start with Brand A, Lemma 9 establishes that they will purchase an upgrade. In this case, the maximum first period price that Firm A could charge would satisfying the following equation:

$$n + \delta_{1a} + \delta_{2a} - p_{1a} - p_{2a}^{u} = 2\delta_b - p_{1b}. \tag{13}$$

The right-hand side of Equation (13) comes from Equation (1) and is the maximum surplus the consumer would expect from choosing Brand B. The left-hand side comes from Equation (3) and represents the expected surplus of a consumer who purchases

Brand A in the first period followed by an upgrade. Therefore, the total price that early adopters pay would be equal to Equation (13) solved for $p_{1a} + p_{2a}^{u}$:

$$p_{1a} + p_{2a}^{u} = n - \Delta_1 - \Delta_2 + p_{1b}. \tag{14}$$

Additionally, it is established that Firm B cannot make any profits in the second period, so Firm B will be willing to price as low as zero in the first period. Thus, $p_{1a} + p_{2a}^{u}$ is equal to $n - \Delta_1 - \Delta_2$. Q.E.D.

Lemma 11: Given that it is possible for the market to fragment (as defined in Proposition 1), early adopters will purchase Brand A in the first period for a price no greater than:

$$p_{1a} = \begin{cases} \gamma n - 2\Delta_2 & \text{if } \Delta_1 < \gamma n \\ -\Delta_1 & \text{otherwise} \end{cases}$$

Proof: It is established that Firm B cannot make any profits in the second period, so in the first period, Firm B is willing to price as low as zero. Therefore, using Lemma 10, the total price that early adopters pay ($p_{1a} + p_{2a}^{u}$) is $n - \Delta_1 - \Delta_2$.

Additionally, there are two different outcomes for the second period, depending on arbitrage. Under the parameter conditions $\Delta_1 < \gamma n$[18], Firm A would expect the early adopters to buy the upgrade for price $p_{2a}^{u} = (1-\gamma)n + \delta_{2a} - \delta_{1a}$. Subtracting

[18] See Lemma 9.

$(1-\gamma)n+\delta_{2a}-\delta_{1a}$ from the total price early adopters pay, $n-\Delta_1-\Delta_2$, means that p_{1a} is equal to $\gamma n-2\Delta_1$, which can be negative[19].

On the other hand, if conditions are such that there is arbitrage in the second period, then subtracting $n-\Delta_2$ from the total price early adopters pay, $n-\Delta_1-\Delta_2$, means that p_{1a} is equal to $-\Delta_1$, which is also negative. Q.E.D.

Lemma 12: Given that it is possible for the market to fragment (as defined in Proposition 1), the market outcome will be either AUA if Δ_2 is less than $3n-\Delta_1$, or BA otherwise. If the market outcome is AUA, Firm A will earn a profit of $2(n-\Delta_2)-\Delta_1$, which breaks down into $n-\Delta_1-\Delta_2$ paid by early adopters and $n-\Delta_2$ paid by late adopters. If the market outcome is BA, early adopters will pay $\Delta_1+\Delta_2-3n$ and late adopters will pay $-n-\Delta_2$.

Proof: Firm A may sell to only the late adopters for a profit $-n-\Delta_2$, but it can also sell to both groups and earn a profit of $2(n-\Delta_2)-\Delta_1$, where $n-\Delta_2$ comes from late adopters and $n-\Delta_1-\Delta_2$ comes from early adopters. Given this choice, Firm A would want to sell to both groups only if $2(n-\Delta_2)-\Delta_1$ is greater than $-n-\Delta_2$, which occurs

[19] Recall the this price is negative because of the assumption of zero marginal costs; thus, such a result should be interpreted as a case where Firm A is willing to price below cost.

only if Δ_2 is less than $3n-\Delta_1$. If Δ_2 is greater than $3n-\Delta_1$, Firm B is free to charge a first period price that keeps Firm A indifferent to competing in the first period; such a price would equate $2(n-\Delta_2)-\Delta_1+p_{1b}$ with $-n-\Delta_2$. Therefore, in the case of outcome BA, p_{1b} will be equal to $\Delta_1+\Delta_2-3n$. Q.E.D.

Therefore, with Proposition 1 and Lemmas 9 through 13, there is enough information to complete the shaded portion of Figure 4. This is summarised in Table 3 below.

Table 3: Boundaries within shaded area of Figure 4.

For $\|\Delta_2\| > n$	
Market outcome	**Boundaries**
AUA	Below $\Delta_2 = 3n-\Delta_1$
BA	Above $\Delta_2 = 3n-\Delta_1$

Lemmas 11 and 12 show an interesting result that is also found in Katz and Shapiro (1986). There will be conditions such that outcome AUA is more profitable for Firm A than outcome BA ($\Delta_2 \le 3n-\Delta_1$), yet the total profit Firm A makes off the early adopters is negative ($n-\Delta_1-\Delta_2<0$ or $\Delta_2>n-\Delta_1$). Under such circumstances, the rate of technological progress is moderate and the network benefit is low. This is where early adopters' willingness to pay for Brand A in the first period is not especially high. If pricing were constrained to marginal cost, early adopters would rather choose Brand B, but this would fragment the market. Because late adopters value the network benefit, Firm A will be able to extract enough of their surplus to subsidise competition. In effect, Firm A is internalising the network externality by paying early adopters (through a below-cost price) for the benefit they confer on late adopters. Provided that Δ_2 is less than $3n - \Delta_1$, Firm A can charge a high enough price to the late adopters in the second period such that outcome AUA is more profitable than outcome BA. Otherwise, if either the network benefit or Firm A's first period quality disadvantage is large, then the cost of subsidising first period competition may not be profit maximising. In this case, the most profitable outcome for Firm A is outcome BA.

So far, the analysis has been confined to the case where Δ_2 is large compared to the network benefit. Section 4.2 will explore the case where Δ_2 is small relative to the network benefit.

4.2 CASE TWO: THE MARKET WILL ALWAYS STANDARDISE

The circumstances under which the network benefits are "large" compared to quality differences are discussed next. This is shown as the non-shaded portion of Figure 4. In this case, network benefits are so important that late adopters will always follow the choice of the early adopters, implying that the market will always be standardised. Just as in the case where network effects are comparatively small, it will be found that Firm A finds it profitable to price below cost in the first period. This a profitable strategy even for some cases where its quality disadvantage in the first period outweighs its quality advantage in the second period.

Despite the fact that late adopters will not necessarily use Brand A, some conclusions remain unchanged from the previous section. Firm A still stands to earn $n - \Delta_2$ from the late adopters, should the early adopters already use Brand A. Early adopters, on the other hand, will pay a slightly lower combined price for both versions of Brand A.

Lemma 13: The total price that early adopters pay for both versions of Brand A will be:

$$p_{2a}^{u} + p_{2a}^{n} = -\Delta_1 - \Delta_2$$

Proof: Given that early adopters start with Brand A, Lemma 9 establishes that they will purchase an upgrade. In this case, the maximum first period price that Firm A could charge would satisfying the following equation:

$$n + \delta_{1a} + \delta_{2a} - p_{1a} - p_{2a}^{u} = n + 2\delta_{b} - p_{1b}. \qquad (15)$$

The right-hand side of Equation (15) comes from Equation (1) and is the maximum surplus the consumer would expect from choosing Brand B. The left-hand side comes from Equation (3) and represents the expected surplus of a consumer who purchases Brand A in the first period followed by an upgrade. Therefore, the total price that early adopters pay would be equal to Equation (15) solved for $p_{1a} + p_{2a}^{u}$:

$$p_{1a} + p_{2a}^{u} = -\Delta_{1} - \Delta_{2} + p_{1b}. \qquad (16)$$

Additionally, it is established that Firm B cannot make any profits in the second period, so Firm B will be willing to price as low as zero in the first period. Thus, $p_{1a} + p_{2a}^{u}$ is equal to $-\Delta_{1} - \Delta_{2}$, which is less than in Lemma 10. Q.E.D.

The total price that early adopters pay is smaller than in Lemma 10 because early adopters know that the market will always standardise. Therefore, the network benefit does not influence the purchase decision for early adopters as no matter what they choose, they will always receive the network benefit.

However, because Firm A no longer has the option of selling to only the late adopters, its next best alternative to competing in the first period is zero profits. Because late adopters only choose the brand that their predecessors have chosen, the consequence of Proposition 1 is that the firms will be competing for control of second period sales in the first period. Therefore, first period price offers will reflect how each firm values the right to sell to the late adopters. Although it is known what is at stake for Firm A should it win the second period (from Proposition 1 and Lemma 13, p_{2a}^{n} and $p_{1a} + p_{2a}^{u}$ are known), it is now necessary to evaluate Firm B's second period profits, should early adopters use its product.

Lemma 14: Given that the market will always standardise (as defined in Proposition 1) and that early adopters use Brand B in the first period, Firm B stands to earn a positive profit of $n + \Delta_2$ in the second period.

Proof: Recall that early adopters are not permitted to change brands midway through the game, so if early adopters start with Brand B, Firm A will only be willing to price as low as zero for the late adopters in response. Therefore, given that early adopters start with Brand B, the maximum that Firm B can charge to the late adopters will satisfy the equation:

$$\delta_{2a} - p_{2a} = n + \delta_b - p_{2b}. \tag{17}$$

The left hand side of Equation (17) represents the net benefit to the late adopter of choosing Brand A, while the right hand side represents the net benefit of choosing Brand B. Because the minimum that Firm A is willing to price is zero, Equation (17) solves for $p_{2b} = n + \Delta_2$. Under Proposition 1, this is a positive number; so Firm B can profitably sell to late adopters. Q.E.D.

From the perspective of the first period, each firm has something to gain by capturing the loyalty of the early adopters. Whoever wins the bidding war in the first period will be able to profit in the second period. Therefore, provided that Firm A can outbid Firm B and still make a positive profit, the market will standardise on Brand A. This is covered in Lemma 15.

Lemma 15: Given that the market will always standardise (as defined in Proposition 1), the market outcome will be AUA if Δ_2 is less than $-\frac{1}{3}\Delta_1$. If Δ_2 is greater than $-\frac{1}{3}\Delta_1$, then the market will standardise on Brand B.

Proof: Each of the two firms have something to gain in the second period should they win the first period. Firm A will earn profits from the late adopters equal to $n - \Delta_2$ plus positive profits from offering an upgrade[20]. Firm B, on the other hand, will earn profits from the late adopters only, equal to $p_{2b} = n + \Delta_2$ (Lemma 14). Both firms will be willing to price below cost, as long as their total profits remain non-negative. For example, Firm B's minimum first period price offer will be equal to $-n - \Delta_2$.

Firm A's profits from winning the first period competition would be equal to the sum of p_{1a}, p_{2a}^u, and p_{2a}^n. From Proposition 1, p_{2a}^n is equal to $n - \Delta_2$ and Lemma 13 states that $p_{1a} + p_{2a}^u$ is equal to $-\Delta_1 - \Delta_2 + p_{1b}$. Thus, Firm A's total profits are equal to $n - \Delta_1 - 2\Delta_2 + p_{1b}$.

Since it is established that Firm B's zero-profit bid in the first period is $-n - \Delta_2$, if Firm A is to out bid Firm B, its total profit would be $-\Delta_1 - 3\Delta_2$. Therefore, profits are positive and outcome AUA will occur if Δ_2 is less than $-\frac{1}{3}\Delta_1$.

If Δ_2 is greater than $-\frac{1}{3}\Delta_1$, then Firm A's profits would be negative if it attempted to out bid Firm B. In this case, Firm B wins the first period competition with a price equal to $p_{1b} = -n + \Delta_1 + 2\Delta_2$, and outcome BB results. Q.E.D.

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[20] Recall that upgrade profits are positive, see Lemma 9.

Lemma 15 illustrates that Firm A can capture the entire market even if its quality disadvantage in the first period outweighs its quality advantage second period. Late adopters are willing to pay just as much for Brand A as the previous section provided that early adopters use the same brand. As such, Firm A can only sell to both groups or it will fail to sell to either, but because selling to both groups will yield a positive profit to Firm A when Δ_2 is less than $-\frac{1}{3}\Delta_1$, AUA will be the outcome. Otherwise, if the network benefit is small or Firm A's quality disadvantage in the first period is large, it will become more costly to subsidise competition in the first period. In this case, Firm B will be able to capture the entire market. This is summarised in Table 4.

Table 4: Boundary within the non-shaded area of Figure 4.

For $\lvert\Delta_2\rvert \le n$	
Market outcome	**Boundaries**
AUA	Below $\Delta_2 = \frac{1}{3}\Delta_1$
BB	Above $\Delta_2 = \frac{1}{3}\Delta_1$

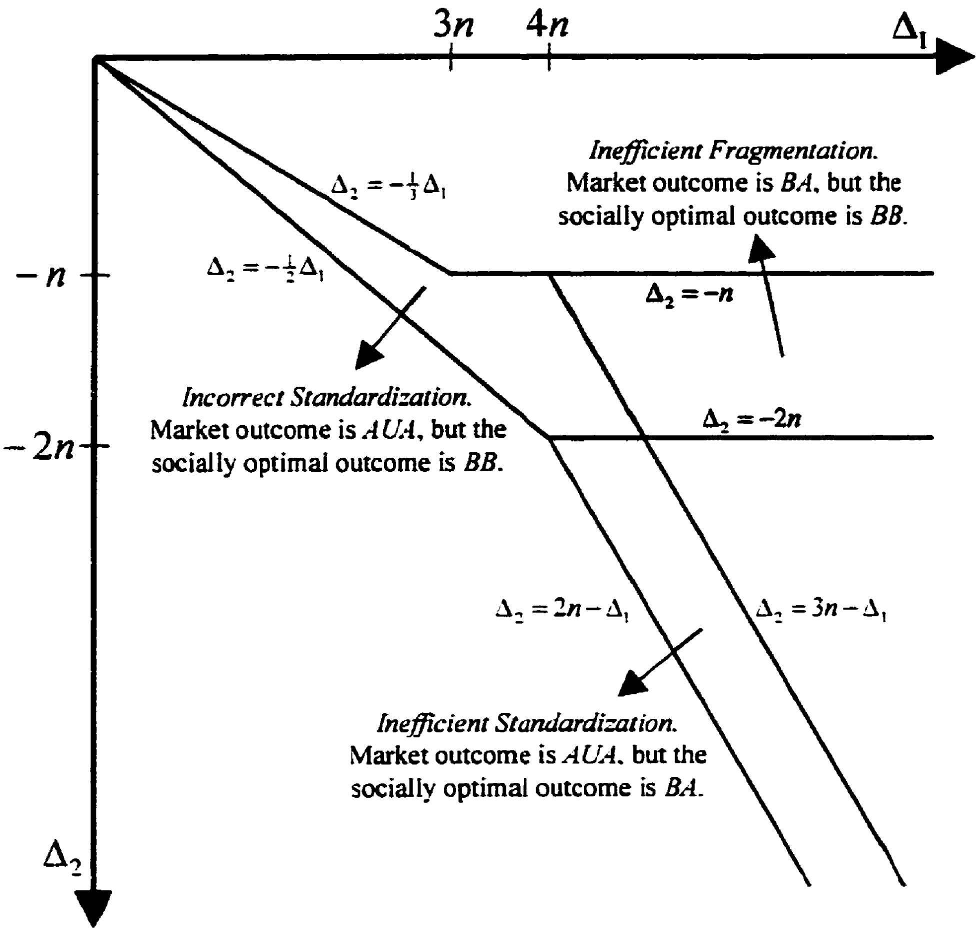
Lemma 15 also shows a result that is similar to Katz and Shapiro (1986) in that the market outcome will always be standardisation when network effects are strong relative to Δ_2. Given that Δ_1 is equal to $\lvert\Delta_2\rvert$, Firm B could just as easily capture the entire market, but it cannot because of Firm A's second mover advantage. Just as in the case where Δ_2 was large relative to the network effect, Firm A can still appropriate surplus from the late adopters to subsidise competition in the first period. Because it has a better product in the second period, Firm A can extract more surplus than Firm B ever could, thus allowing it to bid even lower in the first period.

4.3 WELFARE ANALYSIS

Figure 5 outlines the areas of inefficiency when there are no competitive upgrades. Present are the three sources of inefficiency as identified by Katz and Shapiro (1986). They are incorrect standardisation, inefficient standardisation, and inefficient fragmentation. Incorrect standardisation and inefficient standardisation are due to the fact that a single firm sponsors each technology. This makes it possible for Firm A to have a second-mover advantage in which it can subsidise competition in the first period with expected profits in the second period.

Inefficient fragmentation is caused when late adopters do not take into account their impact on their predecessor's network benefit: this is a result of network effects and is not caused by the strategic interaction of firms. Although upgrades have no effect on the second-mover advantage, there is some change to the instances of inefficient fragmentation. Recall that inefficient fragmentation occurs when early adopters start by purchasing Brand B, which is superior in the first period. In the second period, late adopters purchase Brand A because of its superior quality, but they do not account for the fact that everyone would be better off if they chose the Brand B. Upgrades change this outcome because they allow early adopters the opportunity to use the better version of Brand A in the second period, making it more valuable in the first period. This increases the likelihood that they purchase Brand A in the first period instead of Brand B. Consequently, there is an increase the instances of the market outcome AUA at the expense of BA. Additionally, as discussed earlier, Brand A is the socially preferred choice because early adopters can upgrade. This means that W_{AUA} is greater than W_{BB} for a wider range of parameters. Therefore, with fewer cases of a socially optimal BB outcome and fewer cases of a BA market outcome, there will be fewer cases of inefficient fragmentation.

Figure 5: Welfare analysis; with upgrades, but without competitive upgrades.



Therefore, although upgrades increase the instances of standardisation on Brand A, they also increase the instances where it is socially optimal to standardise on Brand A because Brand A is more valuable. The introduction of upgrades will have no effect on the instances of inefficient standardisation and incorrect standardisation because upgrades do not change the market outcome relative to the socially optimal outcome. This means that the second-mover advantage does not change. As far as early adopters are concerned. their extra payment in the second period cannot be used to subsidise their purchase in the first period.

5 MARKET EQUILIBRIUM: CONSUMERS ARE NOT LOCKED-IN

Chapter 5 changes the model presented earlier to allow competitive upgrades. The consequences of this change are that both the early adopters and Firm A have more choice and flexibility. Early adopters now have the option of using the best technology in each period and Firm A now has the option of bypassing the first period, but still being able to sell to the early adopters. Under these circumstances, the market outcome shown in Figures 6 through 9 is achieved. The shaded regions of each figure represent where Firm A's quality advantage in the second period is large relative to the network benefit.

Figure 6: Outcome for very small switching costs ($\theta \leq n$).

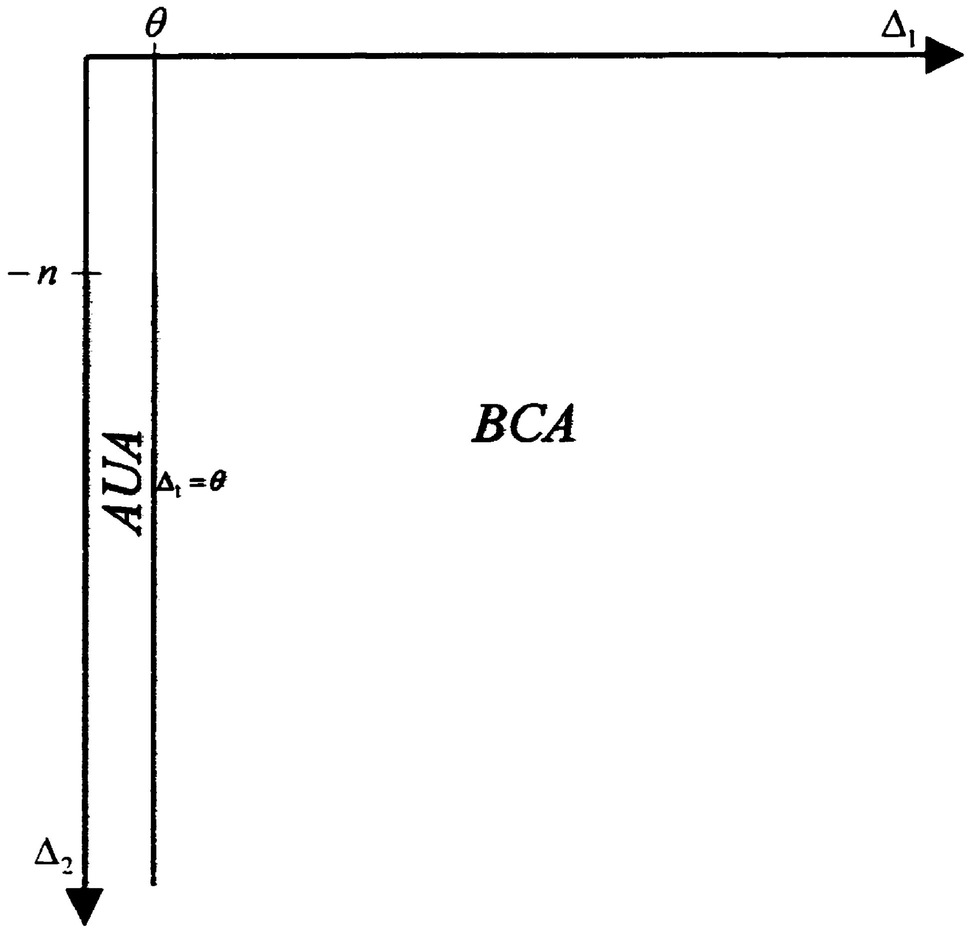


Figure 7: Outcome for small switching costs ($n < \theta < 3n$).

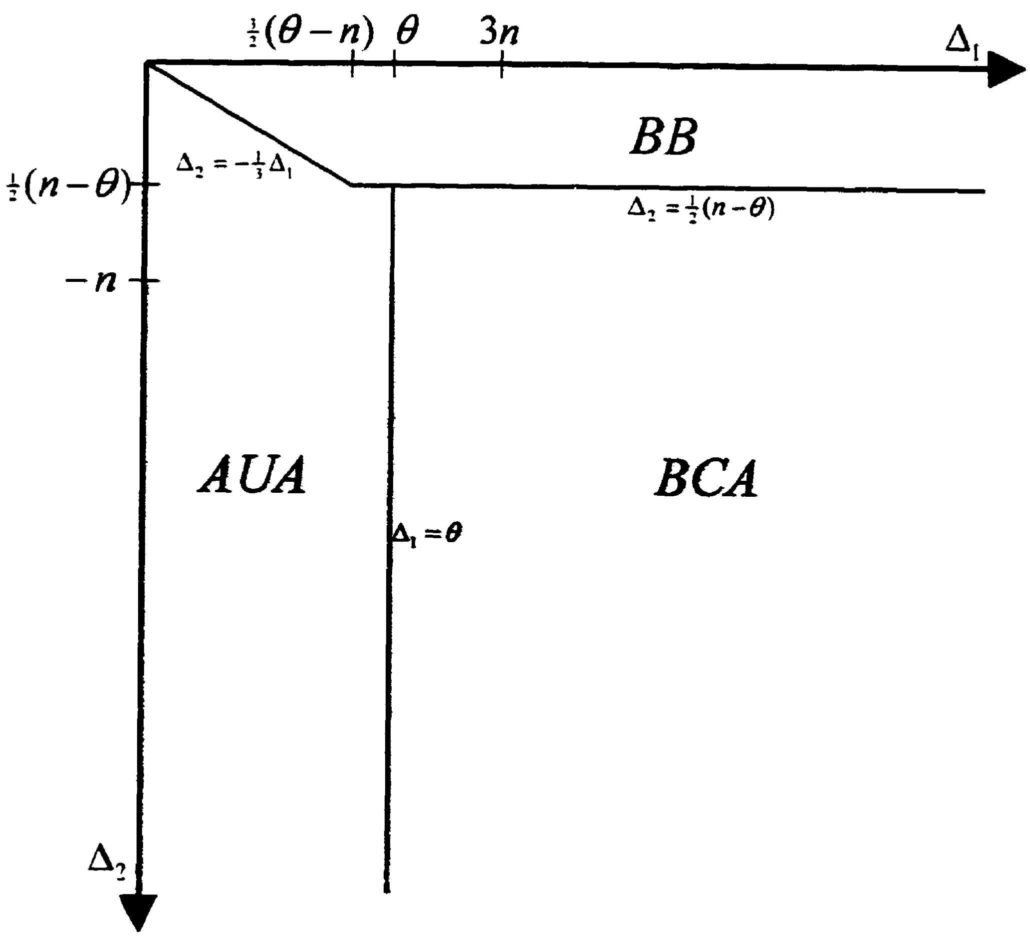


Figure 8: Outcome for large switching costs ($3n \le \theta \le 4n$).

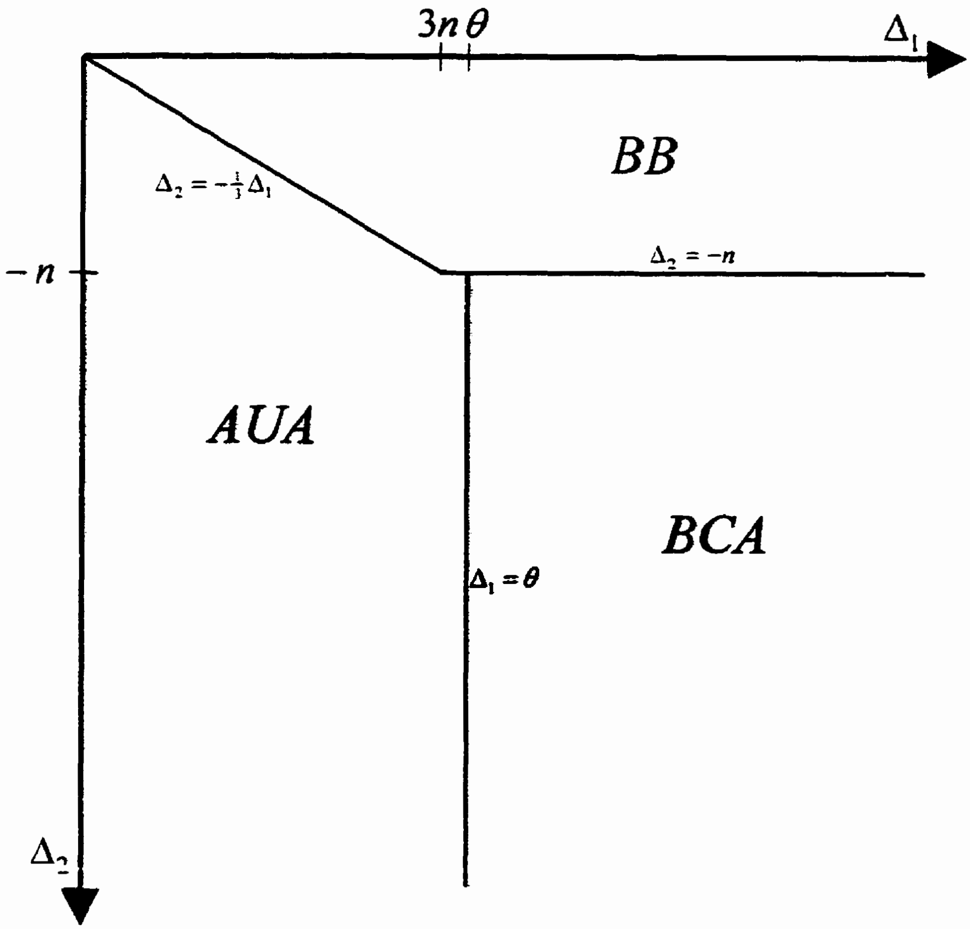
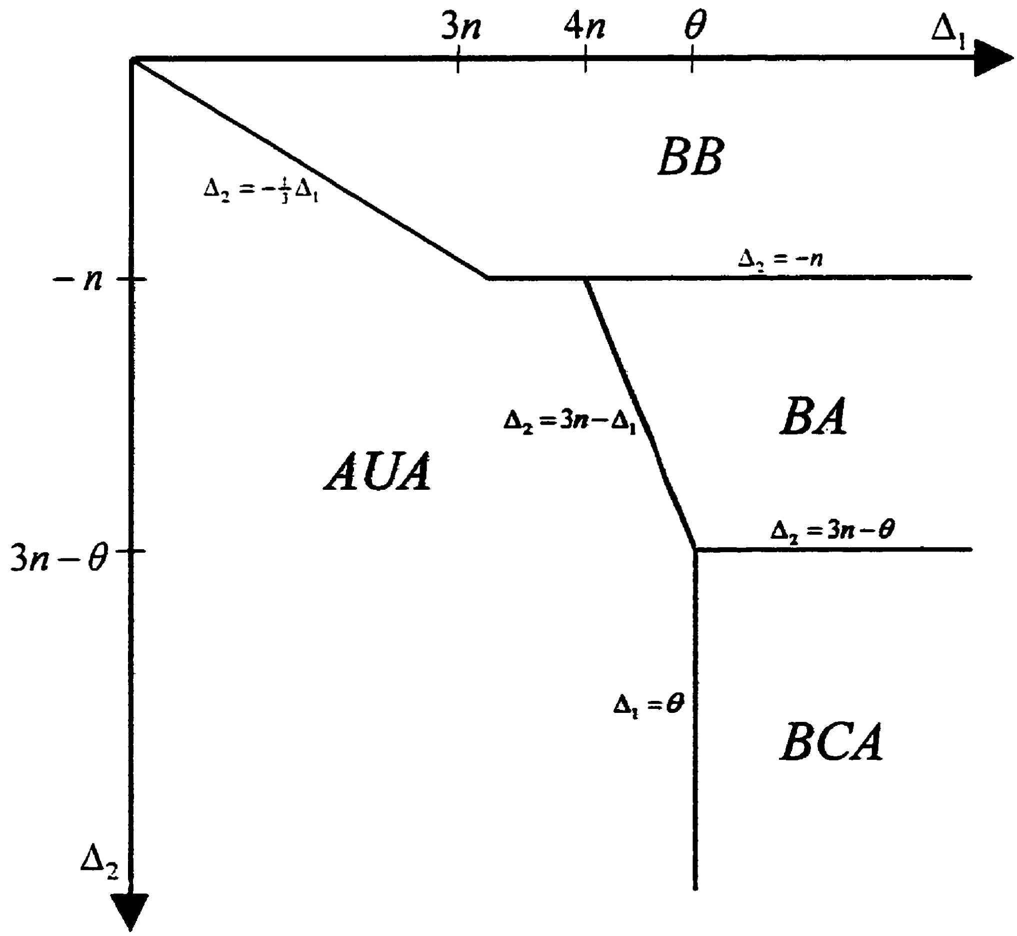


Figure 9: Outcome for very large switching costs ($\theta > 4n$).



Figures 6 through 9 represent the market outcome when there are competitive upgrades. This section finds that once early adopters start by using Brand B, Firm A's competitive upgrade outcome profits are a function of the benefits of standardisation on Brand A and the costs of offering the competitive upgrade. The cost of offering the competitive upgrade is that the switching cost reduces the early adopters willingness to pay for the competitive upgrade. The benefits of standardising on Brand A are that early adopters are willing to pay a price that is a function of Firm A's second period quality advantage, $|\Delta_2|$, which is captured on the vertical axis of each diagram, and all consumers willingness to pay increases because of standardisation. The size of the network benefit relative to the switching cost cannot be represented in (Δ_1, Δ_2) space, thus Figures 6 through 9 represent the market outcome for varying levels of θ. Figure 6 represents the case of very small switching cost, while Figures 7, 8, and 9 represent the cases of small, large, and very large switching costs respectively. Figure 9 will be discussed first because it is the most similar to Figure 4, the market outcome without competitive upgrades. This will allow the discussion to focus on how competitive upgrades impact the model as switching costs are gradually decreased from infinity (Figure 4) to very large (Figure 9) to very small (Figure 6).

A boundary that appears in all four figures is the line $\Delta_1 = \theta$. This represents the boundary where Firm A is indifferent between strategies AUA and BCA. The only difference between the two outcomes is in which period Firm A sells to the early adopters. The left-hand side of the equation, Δ_1, is a reflection of how much Firm A will have to subsidise competition in the first period. It can also be considered the cost of selling to early adopters in the first period. On the right-hand side of the equation, the parameter θ is a measure of how low Firm A will have to price in the second period in order to convince early adopters to switch brands. This can be considered Firm A's cost of using the competitive upgrade in the second period. Therefore, given that Firm A's profit maximising strategy is to standardise the market, it will choose the cheapest method, which will depend on the values of Δ_1 and θ.

Figure 9 represents the case of the largest switching costs, where θ is greater than $4n$. If Firm A used strategy BCA when it is possible for the market to fragment, its profit would be made up of $2n$ plus $2 \cdot |\Delta_2|$, which it can extract from both consumer groups due to their willingness to pay for network benefits and technological progress. From this total, Firm A must subtract θ, which represents what early adopters demand in compensation for switching brands. If Firm A only sold to the late adopters, the profits it could extract from the late adopters from strategy BA would increase with Brand A's quality advantage, but decrease with the network benefit because of the increasing cost to late adopters of not standardising. Therefore, the difference in profit between the two is

$3n + |\Delta_2| - \theta$, where $3n + |\Delta_2|$ is the benefit of offering a competitive upgrade and θ is the cost.

Thus, Figure 9's boundary between BCA and BA is $|\Delta_2| = \theta - 3n$. This marks the point where if early adopters start using Brand B, Firm A is indifferent between converting early adopters over to Brand A with a competitive upgrade or just to selling to the late adopters. This boundary depends on three factors: $|\Delta_2|$, $3n$, and θ. The parameters $|\Delta_2|$ and $3n$ represent the benefits to Firm A from standardising the market by using the competitive upgrade. Early adopters' willingness to pay increases with the quality advantage of Brand A in the second period as well as the network benefit associated with standardising. Since Firm A can profitably sell to the late adopters either way, their willingness to pay will only increase with n. Additionally, Firm A's profits from strategy BA is also decreasing with n. As n increases, strategy BA becomes less attractive because Firm A must offer a lower price to late adopters to compensate them for not following the choice of early adopters. Finally, θ represents the cost of strategy BCA because as θ increases, Firm A must lower its competitive upgrade price to compensate early adopters for learning a new product.

Figure 8 represents the case when θ is between $3n$ and $4n$. Once θ is less than $4n$, Firm A's cost of offering a competitive upgrade will be low enough such that offering a competitive upgrade will always be more profitable than just selling to late adopters. Therefore, it is no longer possible for strategy BA can no longer be profit maximising and it no longer appears as a possible market outcome. However, as long as θ is greater than $3n$, Firm A's competitive upgrade strategy can never earn positive profits when the market would otherwise standardise on Brand B. If Firm A used strategy BCA when the market always standardises, its profits would be made up of n, which it extracts from late adopters, plus $2 \cdot |\Delta_2|$ which it extracts from both consumer groups. Because early adopters must be compensated for switching, θ will decrease Firm A's profits. Therefore, if θ is greater than $3n$, Firm A's cost of strategy BCA is greater than the benefit of $n + 2|\Delta_2|$ and profits would be negative. This means that once early adopters start with Brand B and $|\Delta_2|$ is less than the network benefit, Firm A's profit maximising strategy is to be inactive (outcome BB). In this region, the rate of technological progress is not high enough to make a competitive upgrade profitable when the market always standardises.

Figure 7 marks the point where it is now possible for Firm A to use the competitive upgrade when the market always standardises. The switching cost is now between n and $3n$, which means that the consumers' willingness to pay for standardisation is greater relative to θ than it was in Figure 8. This time, θ is less than $3n$ which means that strategy BCA can be a profitable strategy even when the market standardises. Thus, the boundary between strategy BCA and BB is $|\Delta_2| = \frac{1}{2}(\theta - n)$. This is the zero-profit line where, given that early adopters start with Brand B in the first period, Firm A is indifferent between winning the competition for all consumers or conceding the market to Firm B. The parameters $2 \cdot |\Delta_2|$ and n are benefits to Firm A from choosing strategy BCA; $2 \cdot |\Delta_2|$ represents the increased willingness to pay for Brand A by both consumer groups, while n is what late adopters are willing to pay for the network benefit.

Figure 6 represents the case of the smallest switching costs. In this case, θ is small enough that Firm A's competitive upgrade strategy will always yield positive profits. This means that it can profitably out-bid Firm B for late adopters in the second period. Thus, when the market always standardises (i.e. $|\Delta_2|$ is less than n), it is possible for Firm A's profits from strategy BCA to be positive. Recall from the discussion of Figure 7 that Firm A's profits in this case are comprised of $2 \cdot |\Delta_2|$ plus the network benefit minus the switching cost, which it extracts from consumers in the second period. Without making any assumptions regarding the size of $|\Delta_2|$, this is only positive if θ is less than n. With Firm A's strategy of BCA more profitable than BA and BB, the only choice left is the one between BCA and AUA. It is important to point out that as the switching cost approaches zero, there is no cost to Firm A associated with offering an upgrade. As there is still a cost associated with competing in the first period (Δ_1), strategy BCA will always maximise Firm A's profits and the market outcome becomes BCA for all values of Δ_1 and $|\Delta_2|$.

The boundary $\Delta_1 = \theta$ is common to Figures 6 through 9 because Firm A's decision between strategy AUA and strategy BCA is made in the first period, where Δ_1 and θ are the only factors in deciding which of the two is more profitable. If Firm A decides that strategy BCA is more profitable than AUA, it must then compare BCA against two other possibilities in the second period: just selling to the late adopters (BA), or conceding the market to Firm B (BB). The profit maximising strategy will, in part, depend on the parameters that increase the willingness to pay of consumers for Brand A as a standard (i.e. $|\Delta_2|$ and n) and the parameter that decrease willingness to pay for a competitive upgrade (θ). Therefore, if the switching cost is very large relative to n, as it is in Figure 9, outcome BCA will only be the profit maximising strategy for very large values of $|\Delta_2|$. If θ is smaller relative to n, the rate of technological progress ($|\Delta_2|$) does not need to be as large for strategy BCA to yield the most profit. At this point, BCA will always yield more profit than BA because the increased willingness to pay by consumers for standardisation on Brand A will be greater than the switching cost. If θ is small relative to n, Firm A can even earn a positive profit when the rate of technological progress is low. In the case without competitive upgrades, Firm A did not have this opportunity and the market outcome was BB.

The results leading up to Figures 6 through 9 will be derived in much the same manner as Chapter 4. Section 5.1 will deal with the shaded region of Figures 6 through 9 where there is a relatively large quality advantage (It is possible for the market to fragment). Section 5.2 will deal with the non-shaded regions, where network effects are more important (the market will always standardise).

5.1 CASE ONE: IT IS POSSIBLE FOR THE MARKET TO FRAGMENT

Just as in Section 4.1, if the rate of technological progress is high, Firm A's quality advantage will be large relative to the value of the network and it is possible for the market to fragment. This arises from the fact that Firm A will always be able to profitably sell to the late adopters in the second period even if early adopters do not use the same brand. Despite the fact that early adopters may switch brands in the second period, the conditions under which Firm A always has the option of just selling to the late adopters will remain the same. It is established that if early adopters use Brand B, Firm A can command a price of $p_{2a}^{n} = -n - \Delta_2$ from the late adopters. Under Proposition 1, this price is positive when $|\Delta_2|$ is greater than n, which means that Firm A can count on positive profits with outcome BA. However, allowing early adopters to switch brands means that Firm A must now compare the profits in outcome BA with the profits in outcome BCA as well as outcome AUA.

To compare all three outcomes, one must first calculate what early adopters are willing to pay for an upgrade should they start with Brand A and what they would be willing to pay for a competitive upgrade should they start with Brand B. This will be discussed in Lemmas 16 and 17 respectively. Lemma 18 will complete this exercise by evaluating exactly what first period price is necessary to get early adopters to start with Brand A.

Lemma 16: Given that it is possible for the market to fragment (as defined in Proposition 1) and that the early adopters start by using Brand A, early adopters will purchase an upgrade at the price of

$$p_{2a}^{u} = \begin{cases} (1-\gamma)n + \delta_{2a} - \delta_{1a} & \text{if } \Delta_1 < \gamma n \\ n - \Delta_2 & \text{otherwise} \end{cases}$$

.

Proof: By starting with Brand A, early adopters are foregoing the chance to purchase a competitive upgrade to Brand A. In the second period, the market outcome cannot be different than the case of no competitive upgrades. To prove this, assume that the optimal set of prices for Firm A as found in Lemma 9, still apply. The lowest price that Firm B could offer for a competitive upgrade is zero, which would give early adopters a second period surplus of $\delta_b - \theta$. However, the surplus from upgrading, either $\gamma n + \delta_{1a}$ (if Δ_1 is less than γn) or δ_b (otherwise) is larger than $\delta_b - \theta$. The parameter δ_b is larger than $\delta_b - \theta$ by visual inspection, while $\gamma n + \delta_{1a}$ is larger than δ_b because the condition $\Delta_1 < \gamma n$ can be re-written as $\gamma n + \delta_{1a} > \delta_b$, which implies that $\gamma n + \delta_{1a}$ will also be greater than $\delta_b - \theta$. Therefore, once early adopters start with Brand A, Firm B cannot exert enough competitive pressure on Firm A in the second period to make Firm A change its behaviour. Q.E.D.

Lemma 17: Given that it is possible for the market to fragment (as defined in Proposition 1) and that early adopters start with Brand B, early adopters will be willing to switch to Brand A for the price $p_{2a}^{c} = n - \Delta_2 - \theta$. As long as Δ_2 is less than $3n - \theta$, Firm A will prefer to offer the competitive upgrade compared to just selling to the late adopters.

Proof: Early adopters may either switch to Brand A, receiving the benefit of a higher quality product with a network benefit or stay with Brand B. Thus, the maximum competitive upgrade price, p_{2a}^{c}, that Brand A could charge would satisfy $n + \delta_{2a} - \theta - p_{2a}^{c} = \delta_b$ where θ is equal to the cost of switching. Solved for p_{2a}^{c}, the competitive upgrade price is $p_{2a}^{c} = n - \Delta_2 - \theta$. Note that it is possible for p_{2a}^{c} to be negative and that it is always smaller than $p_{2a}^{n} = n - \Delta_2$. Because of the cost of switching, early adopters always value the new version of Brand A less than the late adopters.

However, Firm A will only offer the competitive upgrade if it increases profits. By not selling the competitive upgrade, Firm A would still be able to sell to the late adopters (as found in Proposition 1) and earn a profit of $-n - \Delta_2$. On the other hand, by selling the competitive upgrade, Firm A would be able to increase its profits from late adopters to $n - \Delta_2$. Adding to this the profit from the competitive upgrade, $n - \Delta_2 - \theta$, the total profit Firm A can expect from selling the competitive upgrade would be $2(n-\Delta_2)-\theta$. Therefore, Firm A would prefer outcome BCA to outcome BA only if $2(n-\Delta_2)-\theta$ is greater than $-n-\Delta_2$. This is true only if Δ_2 is less than $3n-\theta$. Q.E.D.

Note that p_{2u}^c depends on three parameters: n, Δ_2, and θ. While p_{2u}^c is increasing in the network benefit and Δ_2, the inverse relationship between θ and p_{2u}^c is unique to the pricing of the competitive upgrade. As the cost of switching rises, p_{2u}^c must fall to compensate the consumer for having to adjust to a different brand.

With Firm A's total profits from outcomes BA and BCA understood, all that is left is to compare them to AUA. The second period benefit to Firm A of having early adopters start with Brand A is established to be equal to the profits from the upgrade (as found in Lemma 16) plus the profits from the late adopters (as found in Proposition 1).

Lemma 18: Given that it is possible for the market to fragment (as defined in Proposition 1) Firm A will prefer to subsidise first period competition and bring about outcome AUA under certain conditions. If Firm A prefers outcome BCA to outcome BA (the conditions under which this is true are discussed in Lemma 17) then Firm A will maximise profit with outcome AUA only if Δ_1 is less than θ. Otherwise, if it prefers outcome BA to BCA, Firm A will prefer outcome AUA to BA if Δ_2 is less than

$3n-\Delta_1$. Early adopters will pay $p_{1a}+p_{2a}^u=n-\Delta_1-\Delta_2$ in the event of outcome AUA, $p_{1b}=\Delta_1+\Delta_2-3n$ in the event of outcome BA, and $p_{1b}+p_{2A}^c=n+\Delta_1-\Delta_2-2\theta$ in the event of outcome BCA.

Proof: Suppose that if early adopters start with Brand B, Firm A will find it more profitable to just sell to the late adopters (it prefers outcome BA to BCA). In this case, if Firm A decides not to compete in the first period, it will not attempt to sell a competitive upgrade in the future. Therefore, Lemmas 11 and 12 still apply. Firm A will prefer subsidising competition in the first period to achieve outcome AUA when Δ_2 is less than $3n-\Delta_1$. In the event of outcome AUA, early adopters will pay a total of $p_{1a}+p_{2a}^u=n-\Delta_1-\Delta_2$, otherwise they will pay $p_{1b}=\Delta_1+\Delta_2-3n$.

Suppose that if early adopters start with Brand B, Firm A finds it more profitable to offer a competitive upgrade (it prefers outcome BCA to BA). Under this scenario, consumers would consume Brand B (with a stand-alone value of δ_b) in the first period, then switch at a cost of θ to Brand A with a stand-alone value of δ_{2a}. This changes the right hand side of Equation (13) to include the benefits of n and δ_{2a} net of p_{2a}^c and the switching cost. Therefore, (13) becomes (18).

$$n+\delta_{1a}+\delta_{2a}-p_{1a}-p_{2a}^u=n+\delta_b+\delta_{2a}-p_{2a}^c-\theta-p_{1b}. \tag{18}$$

After substituting in the competitive upgrade price, as found in Lemma 17, and cancelling terms, Equation (18) simplifies to:

$$n + \delta_{1a} + \delta_{2a} - p_{1a} - p_{2a}^{u} = 2\delta_{b} - p_{1b}. \tag{19}$$

Equation (19) is no different than Equation (13), so the outcome of strategy AUA remains the same, including Firm A's profits of $2(n-\Delta_2)-\Delta_1$ (where p_{1b} is equal to zero and represents Firm B's lowest bid). In comparison, Firm A's profits from strategy BCA are equal to $n-\Delta_2-\theta$ from the competitive upgrade, plus $n-\Delta_2$ from the late adopters, for a total of $2(n-\Delta_2)-\theta$. Therefore, it is more profitable for Firm A to use the strategy of AUA over the strategy of BCA only if Δ_1 is less than θ. If Δ_1 is greater than θ, then Firm B is free to charge a first period price that keeps Firm A indifferent to competing in the first period. Such a price would equate $2(n-\Delta_2)-\Delta_1+p_{1b}$ with $2(n-\Delta_2)-\theta$; thus, in the case of outcome BCA, p_{1b} will be equal to $\Delta_1-\theta$. Q.E.D.

An important aspect of Lemma 18 is that the inclusion of competitive upgrades does not change Firm A's total profits from outcome AUA. This is because Equation (19) is identical to Equation (13), which occurs for two reasons. Recall that Equation (13) represents the pricing conditions under which early adopters are indifferent between choosing Brand A and choosing Brand B. By choosing Brand A first, the possibility of Firm A offering a competitive upgrade is eliminated, so there is no difference between this and the case of no competitive upgrades. By choosing Brand B first, early adopters know that there will be a competitive upgrade offered to them in the second period, so they will have the opportunity to switch to the better brand in the second period. However, because of the high rate of technological progress, Firm A will be able to price the competitive upgrade in such a way that it is exactly equal to the consumers' willingness to pay. Therefore, although Firm A is likely to profit more by offering a competitive upgrade, when early adopters start with Brand B early adopters are left in the same state as they were in the case of no competitive upgrade. Consequently, Firm A's optimal first period price does not change. This conclusion can be summarised in Table 5.

Table 5: Boundaries within shaded areas of Figures 6 through 9.

For $\lvert\Delta_2\rvert > n$	
Market outcome	**Boundaries**
AUA	Below $\Delta_2 = 3n - \Delta_1$ for values of Δ_2 between $-n$ and $3n - \theta$. Otherwise, to the left of θ.
BA	Above $\Delta_2 = 3n - \Delta_1$ for values of Δ_2 between $-n$ and $3n - \theta$.
BCA	Below $\Delta_2 = 3n - \theta$ and right of $\Delta_1 = \theta$

Compared to Section 4.1, allowing consumers to switch brands has the effect of increasing standardisation on Brand A and increasing Firm A's profits whenever early adopters start with Brand B. In Section 4.1, if early adopters started with Brand B it was because Firm A evaluated the net benefit of competing for the early adopters as less than just selling to the late adopters in the second period. However, when Firm A can offer a competitive upgrade in the second period, it has the option of converting the early adopters over to the new technology. Not only will the late adopters be willing to pay more for Brand A when early adopters are on the same network, but it is possible for the competitive upgrade to make a profit as well. Whether or not this is the most profitable option depends on the switching cost.

If the switching cost is high, as in Figure 9, there is only a slight change from the case of no competitive upgrades (see Figure 4). In this case, the cost of switching is high enough that competitive upgrade profit (which decreases with the switching cost) can be less than outcome BA. This is why the area BA still exists in Figure 9. For Firm A to favour the competitive upgrade at all, its quality advantage must be very high, to attract the early adopters. Thus, for high values of $|\Delta_2|$, BCA is preferred to BA.

5.2 CASE TWO: THE MARKET ALWAYS STANDARDISES

Finally, there is the non-shaded area of Figures 6 through 9 where the network effect is large compared to $|\Delta_2|$. This is where Firm A can only profit by selling to the late adopters if it also sells to the early adopters. As in Section 4.2, this implies that the market outcome will always be one of standardisation, but unlike the case of no competitive upgrades, the first period is not necessarily where this standardisation starts to occur. With competitive upgrades, early adopters can start using one product in the first period, but switch to an entirely different product in the second period. Therefore, winning the first period is not enough for either firm to capture the entire market – the fact that early adopters can switch gives the other firm a second opportunity to attract buyers. With this Section ruling out the possibility of early and late adopters using different brands, the remaining possible outcomes will be BB, AUA, or BCA.

As before, Firm A can count on its second period quality advantage to subsidise losses in the first period. To solve for the market outcome in this case, one must determine the equilibrium in the second period given some outcome of the first period. Lemma 19 will find that if early adopters start by using Brand A, Firm A will be able to fight off any competition from Firm B's competitive upgrade. This is because Firm B holds an inferior product in the second period and early adopters would have to incur a switching cost to convert. Therefore, the outcome would be AUA.

Lemma 20, on the other hand, will find that if early adopters start with Brand B, Firm A will not be able to profitably offer a competitive upgrade all of the time. The fact that Firm A can do this some of the time when Firm B cannot is because Firm A holds the superior product in the second period and can offer an upgrade in response to Firm B's competitive upgrade. This is sometimes enough to overcome the cost of switching.

Lemma 19: Given that the market will always standardise (as defined in Proposition 1) and that early adopters start with Brand A, Firm A will be able to continue this market domination in the second period by offering an upgrade priced at $p_{2a}^{u} = -n - \Delta_2$. This will result in Firm A also capturing the late adopters and second period profits equal to $-2\Delta_2$.

Proof: Suppose that early adopters use Brand A in the first period. Given that early adopters are using Brand A, Lemma 9 states that late adopters would be willing to pay $p_{2a}^{n} = n - \Delta_2$ to also use Brand A. Consequently, Firm A would receive a second period profit equal to $p_{2a}^{u} + n - \Delta_2$. However, if early adopters purchase a competitive upgrade and switch to Brand B in the second period, late adopters will also prefer Brand B (remember that the market will always standardise). In this case, Lemma 14 states that late adopters will be willing to pay $p_{2b}^{n} = n + \Delta_2$ for Brand B if early adopters also use Brand B, so Firm B's second period profit would be $p_{2b}^{c} + n + \Delta_2$.

Therefore, in second period competition for the early adopters. Firm A will be willing to lower its upgrade price down to the point where second period profits are equal to zero, which is $p_{2a}^{u} = -n + \Delta_2$. Similarly, Firm B will be willing to price a competitive upgrade at $p_{2b}^{c} = -n - \Delta_2$. Comparing p_{2a}^{u} to p_{2b}^{c}, Firm A's price is lower because its second period quality advantage gives it the potential to earn more profits from the late adopters. Therefore, if Firm A prices the upgrade at the same price as Firm B's lowest bid[21], early adopters would buy the upgrade for $-n - \Delta_2$ and late adopters would buy Brand A for $n - \Delta_2$ (as determined in Proposition 1). The market outcome would be AUA and total second period profits for Firm A would be $-2\Delta_2$, which is greater than zero. Q.E.D.

Lemma 19 shows a result that did not happen in the model without competitive upgrades. When it was not possible for early adopters to switch to Brand B in the second

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[21] Note that at this price, early adopters achieve a higher surplus by purchasing the upgrade than they would by continuing to use the old Brand A so early adopters would be willing to purchase the upgrade. The surplus from purchasing the upgrade would be $n + \delta_{2a} - p_{2a}^{u} = 2n + \delta_b$; compared to the surplus from using the old version of Brand A, $\gamma n + \delta_{1a}$, purchasing the upgrade is desirable.

period, Firm A was able to offer an upgrade price that was exactly equal to the early adopters willingness to pay. However, now that competitive upgrades are permitted, Firm A must be concerned with the possibility of losing both groups to Brand B. Therefore, because Firm A must defend against competition from Firm B, it upgrades the early adopters for below cost just to maintain the opportunity to sell to the late adopters[22].

Lemma 20: Given that the market will always standardise (as defined in Proposition 1) and that early adopters start with Brand B, Firm A can profitably offer a competitive upgrade to the early adopters while also selling to the late adopters. This is so provided that Δ_2 is less than $\frac{1}{2}(n-\theta)$. Therefore if Δ_2 is less than $\frac{1}{2}(n-\theta)$, the market outcome will be BCA; otherwise, the market outcome will be BB.

Proof: Given that early adopters start by using Brand B, the maximum price that Firm A can charge for the competitive upgrade would satisfy Equation (20). Remember that Firm A cannot sell to the late adopters without first selling to the early adopters. Therefore, early adopters also know the market will standardise when the network benefit is large, so the network benefit is irrelevant to their choice. Thus, Equation (20) represents the maximum price that Firm A can charge for the competitive upgrade.

[22] Firm A prices the upgrade at $-n-\Delta_2$, which under Section 5.2 is assumed to be negative. See Proposition 1.

$$\delta_{2a} - p^c_{2a} - \theta = \delta_b \qquad \textbf{(20)}$$

Equation (20) solves for $p^c_{2a} = -\Delta_2 - \theta$. This represents the maximum that Firm A can charge in order to get early adopters to switch, so Firm A will offer this price as long as it can generate positive profits. Selling the competitive upgrade will mean a second period profit equal to $-\Delta_2 - \theta$ from the competitive upgrade plus $n - \Delta_2$ from the late adopters, for a total of $n - 2\Delta_2 - \theta$. Therefore, second period profits are greater than zero, with Firm A's competitive upgrade price offer equal to $-\Delta_2 - \theta$ if Δ_2 is less than $\frac{1}{2}(n-\theta)$. Q.E.D.

Lemma 19 shows that if early adopters start with Brand A, the market will standardise on Brand A. Additionally, Lemma 20 shows that if early adopters start with Brand B, the market may still standardise on Brand A, but only if Δ_2 is less than $\frac{1}{2}(n-\theta)$. If Δ_2 is greater than $\frac{1}{2}(n-\theta)$, then once early adopters start with Brand B the market will standardise on Brand B. Therefore, Firm A has two courses of action in the first period: either offer a first period price low enough to attract the early adopters, which will bring about outcome AUA, or wait until the second period to compete.

Lemma 21: Given that the market will always standardise (as defined in Proposition 1) and Firm A can profitably offer a competitive upgrade in the second period (as defined in Lemma 20), the market outcome will be AUA if Δ_1 is less than θ or BCA otherwise. In this case, early adopters would pay a total of $-\Delta_1 - \Delta_2$ if they started with Brand A and upgraded or $\Delta_1 - \theta$ if they started with Brand B and purchased a competitive upgrade. Otherwise, if Firm A cannot profitably offer a competitive upgrade in the second period, the outcome will be identical to that found in Lemma 15.

Proof: Suppose first that if early adopters use Brand B in the first period, Firm A will be able to successfully offer a competitive upgrade and capture the entire market (Lemma 20 finds the condition for this outcome is $\Delta_2 \leq \frac{1}{2}(n-\theta)$). Therefore, Firm B knows that no matter what the outcome of the first period, it cannot make any positive profits in the second period. As such, Firm B will not be willing to offer a price in the first period that is below zero.

Firm A's profits from winning the first period competition would be equal to the sum of p_{1a}, p_{2a}^{u}, and p_{2a}^{n}. The sum of p_{1a} and p_{2a}^{u} can be found by substituting in the value of p_{2a}^{c} (as found in Lemma 20) into Equation (18).

$$n + \delta_{1a} + \delta_{2a} - p_{1a} - p_{2a}^{u} = n + 2\delta_b - p_{1b} \quad \textbf{(21)}$$

Solving Equation (21) for $p_{1a} + p_{2a}^{u}$ gives $-\Delta_1 - \Delta_2 + p_{1b}$; therefore, the sum of p_{1a}, p_{2a}^{u}, and p_{2a}^{n} [23] is equal to $n - \Delta_1 - 2\Delta_2 + p_{1b}$. Since the minimum that Firm B is

[23] From Proposition 1, p_{2a}^{n} is equal to $n - \Delta_2$

prepared to bid in the first period is zero, Firm A's profits from outcome AUA would be $n-\Delta_1-2\Delta_2$. Compared to Firm A's profits of $n-2\Delta_2-\theta$ from outcome BCA (as found in Lemma 20), Firm A will prefer to wait until the second period to sell a competitive upgrade if Δ_1 is greater than θ. If Δ_1 is greater than θ, then Firm B will be able to charge a price in the first period that keeps Firm A indifferent to entering in the first period. Such a price is equal to the difference between Δ_1 and θ.

Next, suppose that if early adopters use Brand B in the first period, Firm A will not be able to profitably offer a competitive upgrade and the market will standardise on Brand B. In this case, the model is no different than when there are no competitive upgrades. Therefore, Lemma 15 applies and the market outcome will be AUA if Δ_2 is less than $-\frac{1}{3}\Delta_1$ and BB otherwise. Q.E.D.

Therefore, with Lemmas 19, 20, and 21, there is now enough information to complete Table 6.

Table 6: Market outcome for non-shaded areas of Figures 6 through 9.

For $\|\Delta_2\| \leq n$	
Market outcome	**Conditions**
BB	For values of θ less than $3n$, above $-\frac{1}{3}\Delta_1$ and $\frac{1}{2}(n-\theta)$. For values of θ greater than $3n$, above $-\frac{1}{3}\Delta_1$ and $-n$.
BCA	For values of θ less than $3n$, to the right of $\Delta_1 = \theta$ and below $\frac{1}{2}(n-\theta)$. For values of θ greater than $3n$, to the right of $\Delta_1 = \theta$ and below $-n$.
AUA	Below $-\frac{1}{3}\Delta_1$ for values of Δ_2 greater than $\frac{1}{2}(n-\theta)$ and to the left of $\Delta_1 = \theta$ for values of Δ_2 less than $\frac{1}{2}(n-\theta)$

The difference between Sections 3.4.2 and 3.5.2 is that competitive upgrades introduce the possibility of standardising in the second period (*BCA*). While in both cases. network effects make it necessary for a firm to sell to both groups to be profitable. when there are competitive upgrades. the firm has a second opportunity to do this in the second period. For Firm A. this second opportunity is promising, as it would no longer have to compete with an inferior product. This makes a difference by allowing Firm A to extract more surplus. equal to the network benefit. from the early adopters in the second period. Thus. as the cost of switching decreases. the outcome of *BCA* becomes more prevalent. If the cost of switching between brands is low. then Firm A can command a higher competitive upgrade price such that it can displace Brand B from the market. no matter how much of a quality advantage it had in the first period.

5.3 SHOULD EARLY ADOPTERS DELAY THEIR PURCHASE?

As discussed in Chapter Two, a major finding of Choi and Thum (1998) is that early adopters did not use the option to delay their purchase even when it was socially optimal to do so. This occurred because by waiting until the second period, the old technology did not have an installed base advantage, allowing the firm backing the new technology to extract all consumer surplus. This allowed Choi and Thum to conclude that unlike the Katz and Shapiro (1986) result, where the bias was for the new technology, the bias is actually in the favour of the old technology. However, as pointed out in the literature review, Choi and Thum did not allow the *ex post* superior technology to compete in the first period. This eliminates competition in the first period, which reduces the benefits to early adopters from purchasing the *ex post* superior technology in the first period.

One of the major conclusions that can be derived from the model in this paper is that unlike Choi and Thum (1998), early adopters may delay their purchase too much from a welfare perspective instead of not enough. The purpose of this section is to prove this point by showing that: (1) it is never socially optimal for early adopters to wait, and (2) with the exception of one instance where network benefits are relatively small, early adopters will not regret purchasing in the first period. This process begins with Proposition 2.

Proposition 2: It is never socially optimal for early adopters to delay their purchase.

Proof: If early adopters delay their purchase, one must define the following four outcomes:

1. Outcome OAA: early adopters wait until the second period and both groups use Brand A. The welfare outcome is $W_{OAA} = 2n + 2\delta_{2a}$.
2. Outcome OBB: early adopters wait until the second period and both groups use Brand B. The welfare outcome is $W_{OBB} = 2n + 2\delta_b$.
3. Outcome OAB and.
4. Outcome OBA: early adopters wait until the second period and each group uses a different brand. The welfare outcome is $W_{OAB} = W_{OBA} = \delta_{2a} + \delta_b$.

Using Table 1, W_{AUA} is larger than W_{OAA}, W_{BB} is larger than W_{OBB}, and W_{BA} is larger than both W_{OAB} and W_{OBA}. Therefore, it is never socially optimal for early adopters to wait. Q.E.D.

Proposition 2 is not surprising because consumers will benefit from consuming Brand B and switching to Brand A rather than waiting until the second period to use Brand A. Next, Lemma 22 will show what early adopters can expect if they delay their purchase.

Lemma 22: Early adopters will receive a surplus of $n+\delta_b$ by waiting until the second period to make their purchase.

Proof: Suppose that early adopters wait until the second period to purchase. Then the maximum willingness to pay for Brand A by a consumer in either group would satisfy the equation $n+\delta_{2a}-p_{2a}^n=n+\delta_b-p_{2b}$. Given that the minimum Firm B is willing to charge for its product is zero, this equation reduces down to $p_{2a}^n=-\Delta_2$. Hence, an individual's consumer surplus in this case is $n+\delta_{2a}+\Delta_2$ or $n+\delta_b$. Q.E.D.

In contrast, by purchasing in the first period, early adopters' consumer surplus can be one of six possibilities depending on what they purchase and how much they pay for it. Therefore, early adopters' consumer surplus must be calculated for each of the six possible outcomes. Under Section 5.1, when it is possible for the market to fragment, there are three possible outcomes: (1) BA, (2) AUA, or (3) BCA. Under Section 5.2, when the market always standardises, the other three possible outcomes will be (1) BB, (2) AUA, or (3) BCA.

Lemma 23: When it is possible for the market to fragment, an early adopter can expect a surplus equal to either $3n+\delta_{1a}+\delta_{2a}$, $2\delta_b$, or $\delta_b+\delta_{1a}+\theta$ by purchasing in the first period.

Proof: If early adopters use Brand B while late adopters use Brand A, Lemma 18 finds that p_{1b} is equal to $\Delta_1+\Delta_2-3n$. Therefore, early adopters' consumer surplus from using Brand B for two periods is $2\delta_b-p_{1b}$ or $3n+\delta_{1a}+\delta_{2a}$.

If the market outcome is AUA, early adopters can expect a surplus of $n+\delta_{1a}+\delta_{2a}-p_{1a}-p_{2a}^{u}$. Lemma 18 proves that the total amount that an early adopter would pay is equal to $p_{1a}+p_{2a}^{u}=n-\Delta_1-\Delta_2$. Therefore, an early adopter would receive a surplus of $2\delta_b$ should she use Brand A and upgrade.

If the market outcome is BCA, an early adopter can expect a surplus of $n+\delta_b+\delta_{2a}-\theta-p_{1b}-p_{2a}^{c}$. Lemma 18 finds that $p_{1b}+p_{2a}^{c}$ is equal to $n+\Delta_1-\Delta_2-2\theta$. Therefore, an early adopter would receive a surplus of $\delta_b-\delta_{1a}+\theta$. Q.E.D.

Lemma 24: When the market always standardises, an early adopter can expect a surplus equal to either $3n - \Delta_1 + 2\delta_{2a}$, $n + 2\delta_b$, or $n + \delta_b + \delta_{1a} + 2\theta$.

Proof: If the market were to standardise on Brand B, Lemmas 15 and 21 state that p_{1b} is equal to $-n + \Delta_1 + 2\Delta_2$. Therefore, the consumer surplus from using Brand B for two periods is $n + 2\delta_b - p_{1b}$ or $2n - \Delta_1 + 2\delta_{2a}$.

If the market outcome is AUA, an early adopter can expect a surplus of $n + \delta_{1a} + \delta_{2a} - p_{1a} - p_{2a}^u$. Lemma 21 proves the sum of p_{1a} and p_{2a}^u is equal to $-\Delta_1 - \Delta_2$. Therefore, an early adopter would receive a surplus of $n + 2\delta_b$ should she use Brand A and upgrade.

If an early adopter were to use Brand B and purchase a competitive upgrade later, she can expect a surplus of $n + \delta_b + \delta_{2a} - \theta - p_{1b} - p_{2a}^c$. Lemma 20 proves that p_a^c is equal to $-\Delta_2 - \theta$, while Lemma 21 proves that p_{1b} is equal to $\Delta_1 - \theta$. Therefore, an early adopter would receive a surplus of $n + \delta_b + \delta_{1a} + 2\theta$ should she use Brand B and purchase a competitive upgrade later. Q.E.D.

Using Lemmas 22, 23, and 24, one can construct the proof for Proposition 3.

Proposition 3: Early adopters may sometimes regret purchasing in the first period if they purchase Brand A. This will only be true when Brand A has a strong quality advantage in the second period and δ_b is greater than n.

Proof: From Lemma 22, if an early adopter were to delay her purchase, she can expect a surplus of $n+\delta_b$. From Lemmas 23 and 24, if that same early adopter were to purchase in the first period, she can expect one of the following outcomes:

(1) From Lemma 23, when it is possible for the market to fragment and early adopters choose Brand B to start, they can expect a surplus of either $3n+\delta_{1a}+\delta_{2a}$ or $\delta_b+\delta_{1a}+\theta$.

(2) From Lemma 23, when it is possible for the market to fragment and early adopters choose Brand A to start, they can expect a surplus of $2\delta_b$.

(3) From Lemma 24, when the market always standardises and early adopters choose Brand B to start, they can expect a surplus of either $2n-\Delta_1+2\delta_{2a}$ or $n+\delta_b+\delta_{1a}+2\theta$.

(4) From Lemma 24, when the market always standardises and early adopters choose Brand A to start, they can expect a surplus of $n+2\delta_b$.

Cases (3), and (4) show that the surplus associated with purchasing in the first period are never less than the surplus associated with delaying their purchase, as found in Lemma 22. However, within cases (1) and (2) are exceptions. Both exceptions occur when it is possible for the market to fragment. Under this situation, early adopters would regret purchasing in the first period if n is greater than δ_b (in the case of outcome AUA), or if n is greater than $\delta_{1a}+\theta$ (in the case of outcome BCA). Q.E.D.

The conditions under which early adopters regret purchasing in the first period are worthy of discussion. This occurs when Firm A's quality advantage in the second period is large enough to make network effects relatively unimportant. In this case, the high value of $|\Delta_2|$ in relation to n allows Firm A to earn higher profits off the late adopters irrespective of whether they also sell to the early adopters. Therefore, Firm A will only sell to the early adopters if it can increase its profits even more. As such, the firm may be able to extract enough surplus such that the early adopters may regret purchasing in the first period. In the case of outcome AUA, Firm B has neither an installed base nor a superior product in the second period so Firm A can charge a price for the upgrade that extracts all of the early adopters surplus. When δ_b is very small relative to the network benefit, this means that the rate of technological progress must be very high[24], which reduces the benefit to the early adopters of consuming in the first period.

In the case of outcome BCA, early adopters may also have regrets about purchasing in the first period. The conditions for this situation is also very similar: the network benefit is already small and δ_{1a} and θ must be smaller. Therefore, not only will Firm A be able to extract all consumer surplus in the second period, but because δ_{1a} and θ are small it is not profit maximising for Firm A to compete in the first period. This will leave Firm B to extract more consumer surplus in the first period as well.

This result is actually quite different than Choi and Thum (1998). In Choi and Thum, early adopters could only choose between the *ex post* inferior technology and waiting until the second period. However, waiting gave an additional advantage to the *ex post* superior technology in that it did not have to compete against an installed base. This resulted in less competition, which made early adopters worse off than if they purchased the *ex post* inferior technology in the first period instead. Even when it is socially optimal to wait, early adopters purchase in the first period. This caused non-standardisation when

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[24] Remember that this happens when Firm A's quality advantage in the second period is high. Add to this the fact that δ_b is also smaller than the network benefit, and the conclusion must be that $|\Delta_2|$ is very large.

network effects were small and standardisation on the wrong technology when network effects were large.

However, Proposition 2 states that, from a welfare perspective, it is never optimal for early adopters to delay their purchase because they benefit form the extra period of consumption. Additionally, the fact that the *ex post* superior technology may compete in the first period reduces the first period price, which increases the cost of delaying their purchase. It is only when Firm A's quality advantage in the second period is very large that early adopters may wish to delay. For waiting to be an optimal strategy, the network benefit must be large compared to the benefits of using the second-best first period technology. A large value of n enables Firm A to extract all consumer surplus from the early adopters because of the greater value of joining late adopters in using Brand A. Conversely, a small value of δ_b (in the case where early adopters start with Brand A if they purchase in the first period) or a small value of $\delta_{1a}+\theta$ (in the case where early adopters start with Brand B if they purchase in the first period) decreases the value of alternatives in the first period. This reduces the competitive pressures on the brand that early adopters would otherwise use in the first period. Consequently, there will be little competition for early adopters in either period. They would be better off by waiting until the second period in this case, as not being committed to one brand will help increase competition in the second period and lower the price of Brand A.

5.4 SUMMARY OF COMPETITIVE UPGRADES

The results of this model can be summarised in Δ_1, Δ_2 space shown in Figures 6 through 9 and reviewed in Tables 5 and 6. Section 5.1, where the second period quality differential is large compared to network effects, is identified as the shaded areas of each figure and represents the case where network effects are not strong enough to ensure standardisation. With the introduction of competitive upgrades, it was found to be possible to sell to both consumer groups in the second period, but Firm A would only do so if it were more profitable than outcomes BA and AUA. Therefore, with no competitive upgrades, Firm A entered first period competition to bring about outcome AUA only when Δ_2 was larger than $3n - \Delta_1$. With competitive upgrades, Firm A only does this if Δ_2 is larger than $3n - \Delta_1$ *and* Δ_1 is less than the switching cost. This extra condition reflects the fact that if the switching cost (which is inversely related to the competitive upgrade price) is less than the cost of competing in the first period[25], it will be more profitable to wait until the second period to sell to the early adopters, when the costs are lower.

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[25] Remember that Δ_1 represents the technological disadvantage of Brand A in the first period. As the value of Δ_1 increases, Firm A must lower its first period price to compensate early adopters for an inferior product.

In Section 5.2, network effects are large compared to the second period quality differential. This is identified as the non-shaded areas in Figures 6 through 9 and represents the case where the market always standardises. In this case, the introduction of competitive upgrades allows Firm A a chance to reverse what would have been a standardisation on Brand B to a standardisation on Brand A. This is evident for switching costs less than $3n$ as this represents the threshold where Firm A can offer a competitive upgrade to the early adopters for a price that may even be below cost, yet still earn an overall profit that is positive. As the cost of switching decreases, this is even possible when Brand B has an extremely large quality advantage in the first period and Brand A's qualitative superiority over Brand B in the second period is extremely small. The welfare implications of this phenomenon will be discussed in greater detail in Chapter 6.

Additionally, Section 5.3 shows that the conclusions of Choi and Thum (1998) do not apply to this model. Choi and Thum conclude that early adopters do not always use the option to delay their purchase when it is socially optimal. However, this paper concludes that it is never socially optimal to delay their purchase. This reversal can be attributed to Brand A in the first period and competitive upgrades. For low rates of technological progress or high switching costs, early adopters can use Brand A in the first period and will benefit from using the *ex post* superior technology as soon as possible. For high rates of technological progress or low switching costs, competitive upgrades introduce the option to switch brands after the technological lead changes instead of waiting for the new technology to evolve. Therefore, using Brand B in the first period then switching to Brand A is preferable to consuming nothing in the first period before adopting Brand A in the second period; the extra period of consumption can only increase welfare.

Finally, a note about how the competitive upgrade model can be extended to a case where there are no network effects. For illustrative purposes, the shaded area of Figure 9 would most accurately represent the market outcome[26]. Figure 9 is re-drawn as Figure 10 with the assumption of the network benefit equal to zero. This would mean three possible outcomes: AUA, BA, and BCA.

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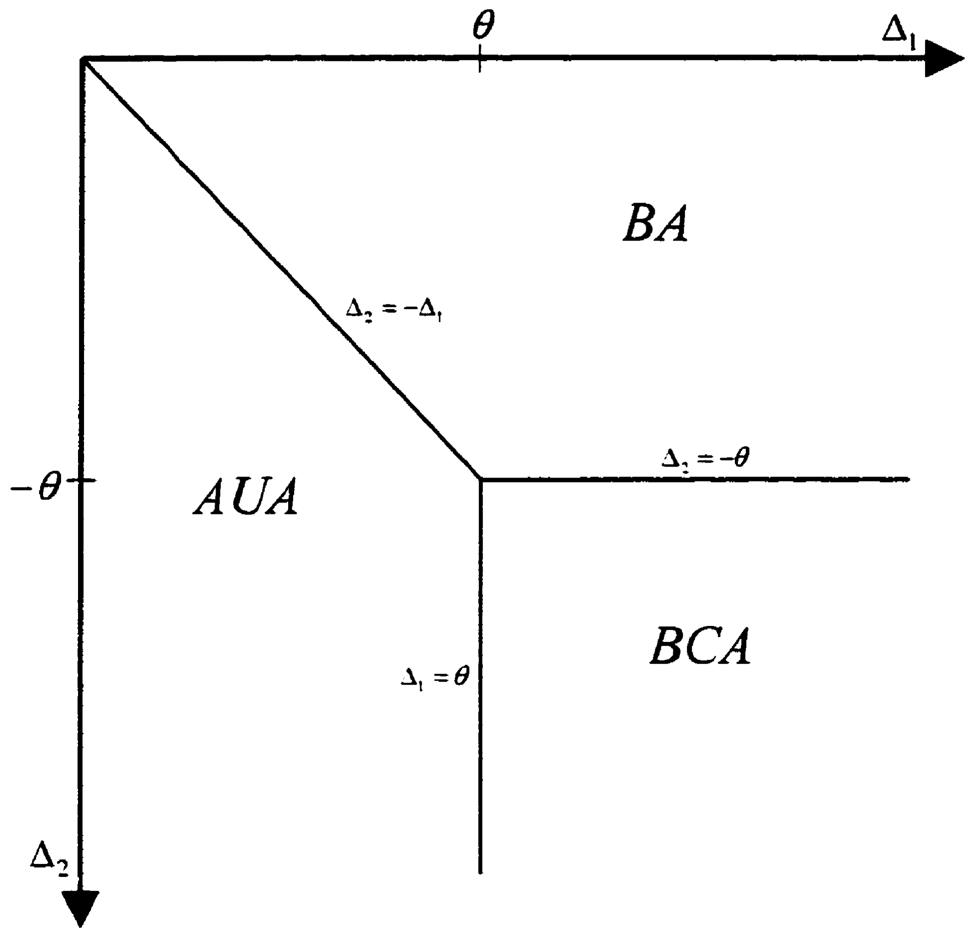
[26] Figure 9 diagrams the case of the smallest network benefit compared to the switching cost. Furthermore, the shaded area of Figure 9 represents the case of a small network benefit relative to Firm A's second period quality advantage.

Figure 10: Competitive Upgrade Model with Network Benefits Equal to Zero.



If Δ_1 and $|\Delta_2|$ are both larger than θ, the outcome would be BCA - the reasons for which can be explained by imagining that either Δ_1 or $|\Delta_2|$ are *not* larger than θ. Suppose first that Δ_1, which represents the disadvantage of Firm A in the first period, is less than θ, the cost to consumers of switching brands. If Δ_1 is less than θ, the degree to which Firm A must price below cost in the first period is less than the cost of getting early adopters to switch in the second period[27]. In this case, Firm A would prefer outcome AUA to outcome BCA.

Now suppose that $|\Delta_2|$ is less than θ. If Firm A's technological advantage in the second period, which is represented by a small value of $|\Delta_2|$, is less than the cost of getting early adopters to switch, then selling a competitive upgrade is not appealing to Firm A. This is because a high value of $|\Delta_2|$, which represents what Firm A stands to earn from the competitive upgrade, is necessary to justify the reduced price it must offer to get consumers to switch.

If both Δ_1 and $|\Delta_2|$ are less than θ, then the choice for Firm A is between outcomes BA and BCA. Firm A will choose whatever action maximises its profits, so it will only attempt to sell to the early adopters if $|\Delta_2|$ (Firm A's technological advantage in

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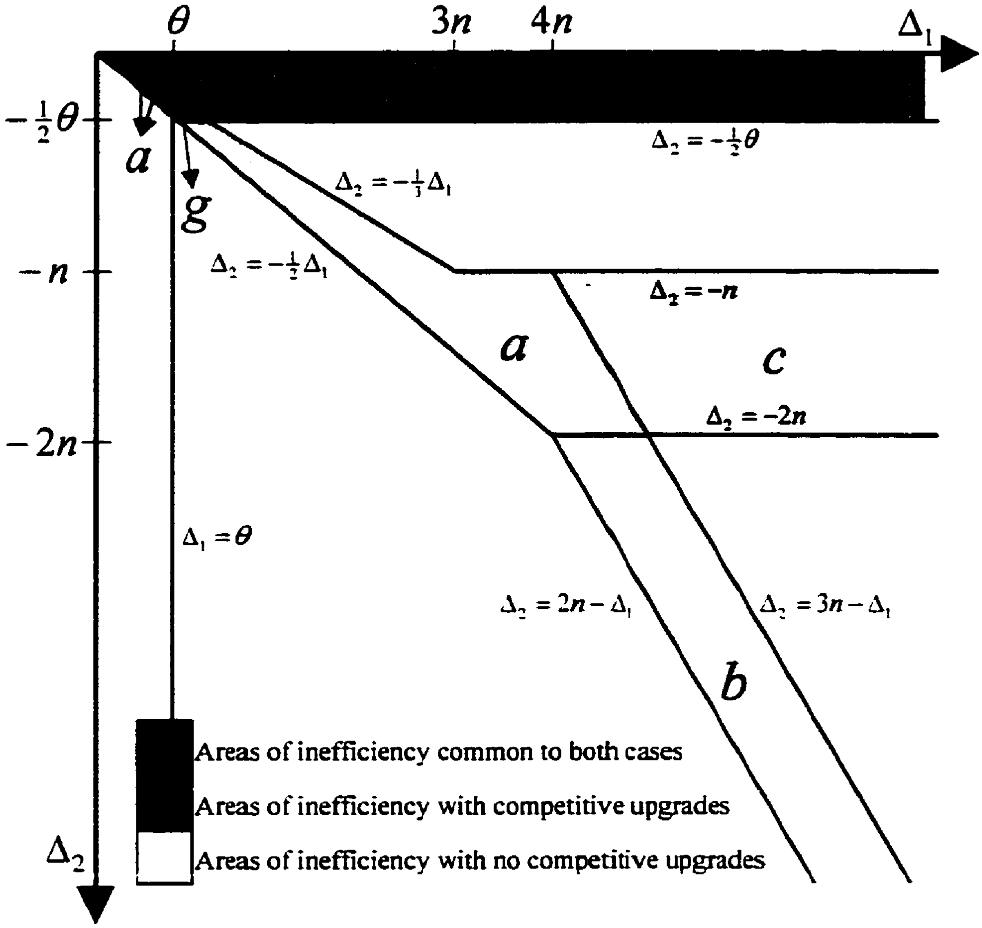
[27] Remember that p_{2a}^{c} is inversely related to θ.

the second period) is greater than Δ_1 (Firm A's technological disadvantage in the first period). If this is the case, the profits Firm A earns on the upgrade, will offset the cost of competing in the first period.

6 WELFARE ANALYSIS OF COMPETITIVE UPGRADES

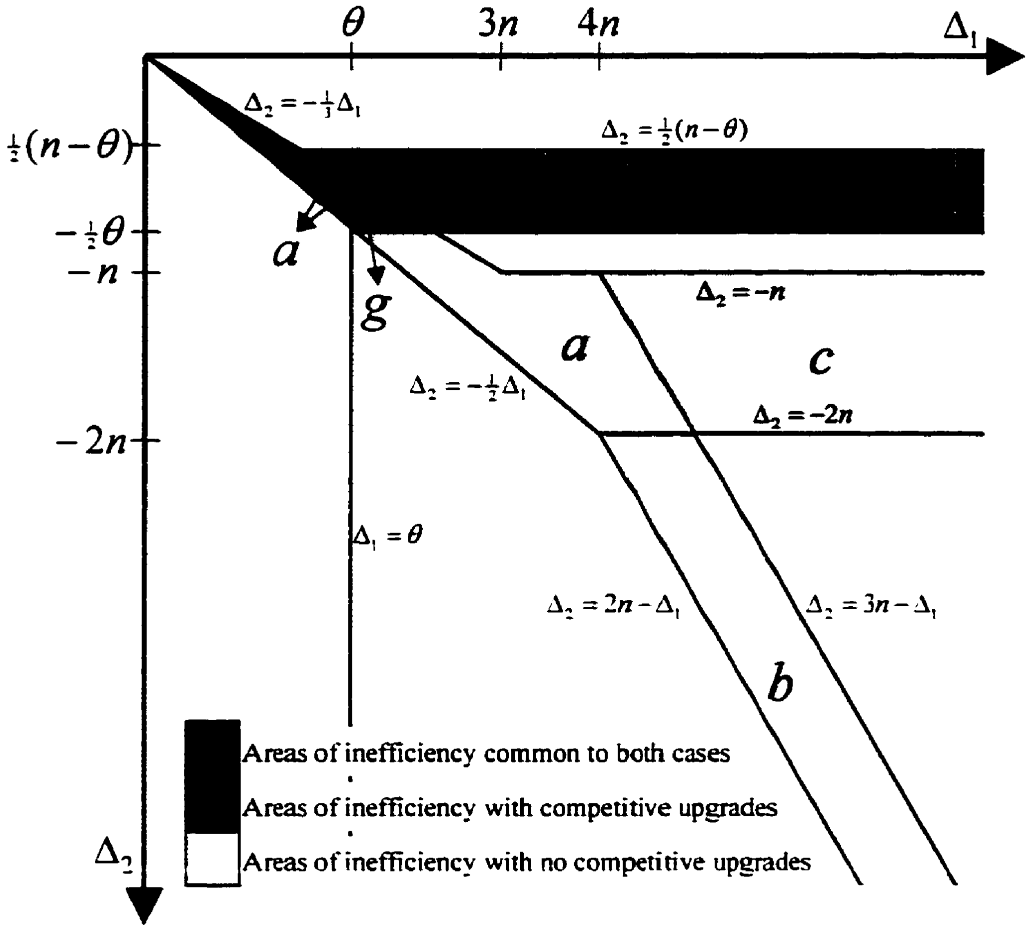
The final step is to analyse the welfare effects of competitive upgrades. To do this, it is necessary to compare the areas of inefficiency in Figure 5 with a similar diagram for each of Figures 6 through 9. The method for constructing Figure 11, the case of very small switching costs, is described to serve as an example of how the other figures are constructed. Figure10 is derived by using Figure 3 superimposed on to Figure 6 to identify the areas of inefficiency for very small switching costs. On top of this, Figure 5 is overlaid to show how the areas of inefficiency change with the addition of competitive upgrades. The remaining three cases are shown in Figure 12 through 15.

Figure 11: Areas of inefficiency for very small switching costs ($\theta \le n$).



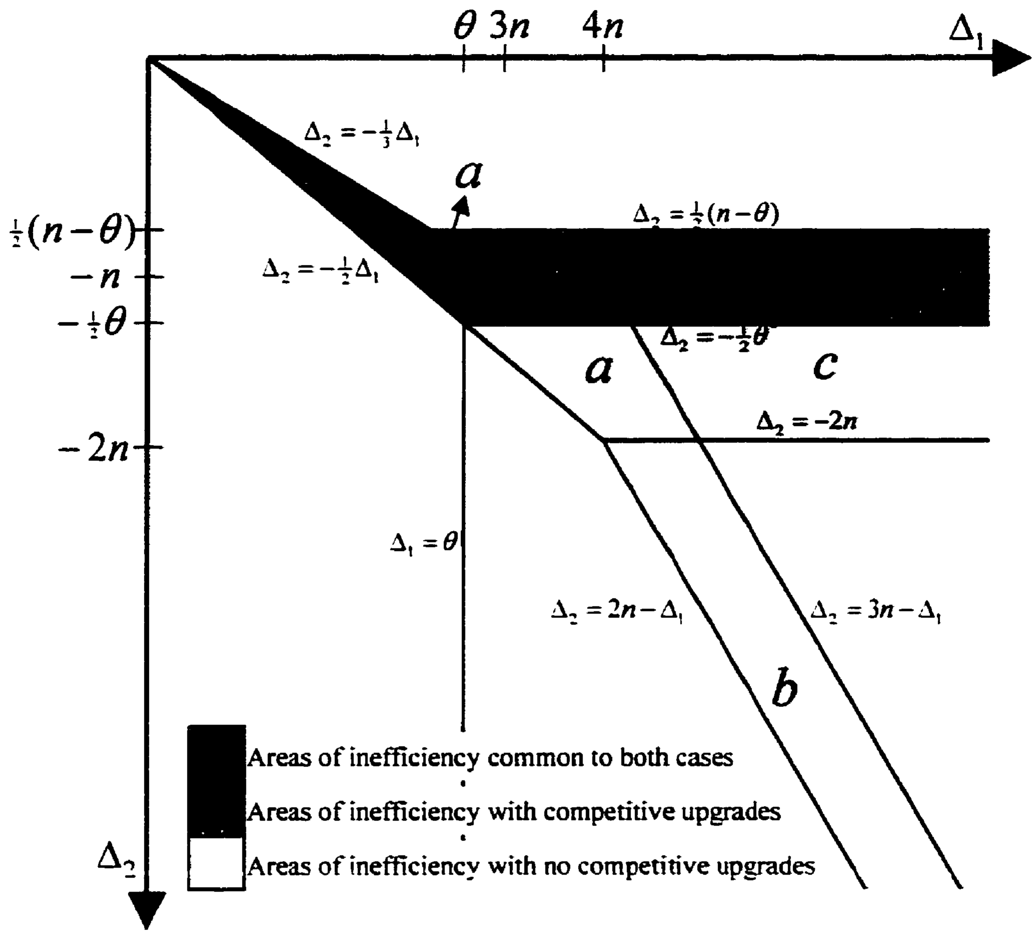
Area	Description of Inefficiency
a	*Incorrect Standardization.* Outcome is *AUA*, but it should be *BB*.
b	*Inefficient Standardization.* Outcome is *AUA*, but it should be *BA*.
c	*Inefficient Fragmentation.* Outcome is *BA*, but it should be *BB*.
d	*Delayed Incorrect Standardization.* Outcome is *BCA*, but it should be *BB*.
e	*Delayed Inefficient Standardization.* Outcome is *BCA*, but it should be *BA*.
f	With no competitive upgrades: area '*c*'. With competitive upgrades: area '*d*'.
g	With no competitive upgrades: area '*a*'. With competitive upgrades: area '*d*'.
h	With no competitive upgrades: area '*b*'. With competitive upgrades: area '*e*'.

Figure 12: Areas of inefficiency for small switching costs ($n < \theta \le 2n$).



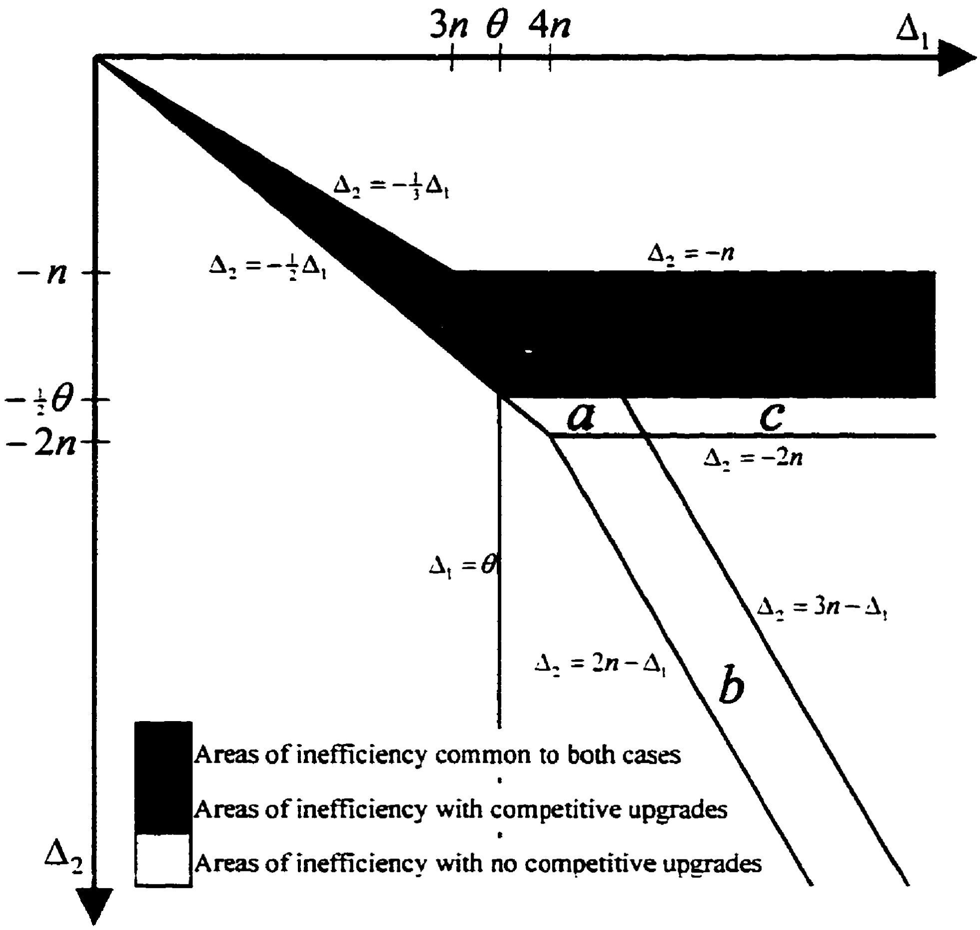
Area	Description of Inefficiency
a	*Incorrect Standardization.* Outcome is AUA, but it should be BB.
b	*Inefficient Standardization.* Outcome is AUA, but it should be BA.
c	*Inefficient Fragmentation.* Outcome is BA, but it should be BB.
d	*Delayed Incorrect Standardization.* Outcome is BCA, but it should be BB.
e	*Delayed Inefficient Standardization.* Outcome is BCA, but it should be BA.
f	With no competitive upgrades: area '*c*'. With competitive upgrades: area '*d*'.
g	With no competitive upgrades: area '*a*'. With competitive upgrades: area '*d*'.
h	With no competitive upgrades: area '*b*'. With competitive upgrades: area '*e*'.

Figure 13: Areas of inefficiency for moderate switching costs ($2n < \theta < 3n$).



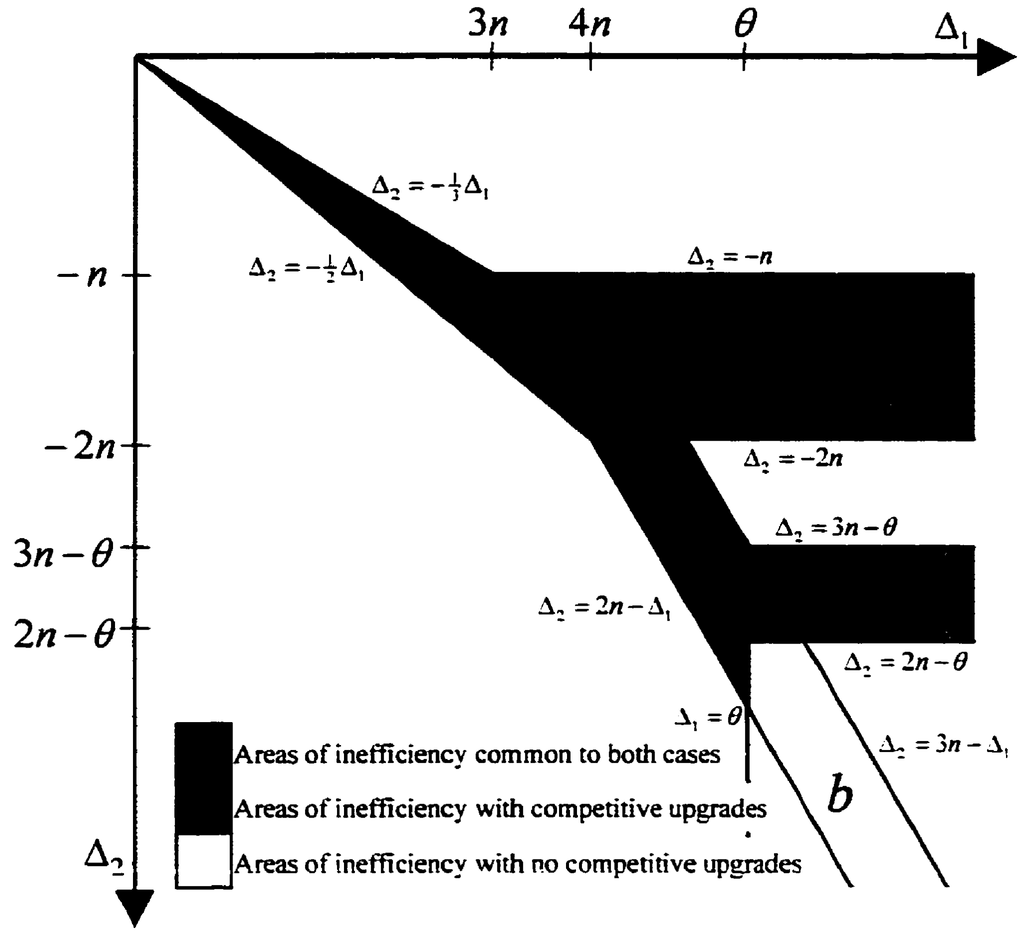
Area	Description of Inefficiency
a	*Incorrect Standardization.* Outcome is AUA , but it should be BB .
b	*Inefficient Standardization.* Outcome is AUA , but it should be BA .
c	*Inefficient Fragmentation.* Outcome is BA , but it should be BB .
d	*Delayed Incorrect Standardization.* Outcome is BCA , but it should be BB .
e	*Delayed Inefficient Standardization.* Outcome is BCA , but it should be BA .
f	With no competitive upgrades: area 'c'. With competitive upgrades: area 'd'.
g	With no competitive upgrades: area 'a'. With competitive upgrades: area 'd'.
h	With no competitive upgrades: area 'b'. With competitive upgrades: area 'e'.

Figure 14: Areas of inefficiency for large switching costs ($3n \le \theta \le 4n$).



Area	Description of Inefficiency
a	*Incorrect Standardization.* Outcome is AUA, but it should be BB.
b	*Inefficient Standardization.* Outcome is AUA, but it should be BA.
c	*Inefficient Fragmentation.* Outcome is BA, but it should be BB.
d	*Delayed Incorrect Standardization.* Outcome is BCA, but it should be BB.
e	*Delayed Inefficient Standardization.* Outcome is BCA, but it should be BA.
f	With no competitive upgrades: area 'c'. With competitive upgrades: area 'd'.
g	With no competitive upgrades: area 'a'. With competitive upgrades: area 'd'.
h	With no competitive upgrades: area 'b'. With competitive upgrades: area 'e'.

Figure 15: Areas of inefficiency for very large switching costs ($\theta > 4n$).



Area	Description of Inefficiency
a	*Incorrect Standardization.* Outcome is AUA, but it should be BB.
b	*Inefficient Standardization.* Outcome is AUA, but it should be BA.
c	*Inefficient Fragmentation.* Outcome is BA, but it should be BB.
d	*Delayed Incorrect Standardization.* Outcome is BCA, but it should be BB.
e	*Delayed Inefficient Standardization.* Outcome is BCA, but it should be BA.
f	With no competitive upgrades: area 'c'. With competitive upgrades: area 'd'.
g	With no competitive upgrades: area 'a'. With competitive upgrades: area 'd'.
h	With no competitive upgrades: area 'b'. With competitive upgrades: area 'e'.

Figures 11 through 15 display the areas of inefficiency from the market outcome with competitive upgrades by comparing the market outcome with the socially optimal outcome. Just as in the discussion of Figures 6 through 9, the market outcome is described for very small switching costs ($\theta \leq n$), small switching costs ($n < \theta \leq 2n$), moderate switching costs ($2n < \theta < 3n$)[28], large switching costs ($3n \leq \theta \leq 4n$), and very large switching costs ($\theta > 4n$). Additionally, in order to compare the effects of competitive upgrades on incorrect standardisation, inefficient standardisation, and inefficient fragmentation, each of these figures is superimposed on top of Figure 5. Therefore, the areas of inefficiency without competitive upgrades are marked with the lightest shading, and the areas of inefficiency with competitive upgrades are marked with medium shading. Areas of overlap are marked with the darkest shading. Just as in the discussion of Figures 6 through 9, the discussion of Figure 11 through 15 will start with the case of the highest switching costs. Therefore, Figure 15 will be discussed first because it is the most similar to Figure 4, the market outcome without competitive upgrades. This will allow the discussion to focus on how competitive upgrades change the inefficiencies in the case without competitive upgrades as switching costs are gradually decreased.

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[28] For the purposes of this section, Figure 7, where switching costs are between n and $3n$ must be divided into two parts. When compared to the welfare outcome in Figure 2, a value of θ between n and $3n$ means that $-\frac{1}{2}\theta$ (a point on Figure 2) can be both greater than and less than $-n$ (a point on Figure 7). Because this does not appreciably change the discussion of the welfare effects of competitive upgrades, Figures 12 and 13 are dealt with in the same space.

In Figure 15, inefficient standardisation, or area 'b', is the only one of the three Katz and Shapiro (1986) inefficiencies to be effected by competitive upgrades. Area 'b' represents the case where the market outcome is AUA, but it should be BA. However, in the case with competitive upgrades, this situation is replaced with an efficient BCA outcome. Recall from the discussion of Figure 9 that switching costs are so high in this case that Firm A's strategy of BCA is only used for the highest values of $|\Delta_2|$ relative to Δ_1. Inefficient standardisation is caused by Firm A's second-mover advantage, allowing it to subsidise competition in the first period and bring about outcome AUA. When the rate of technological progress is high, then the market should fragment and when it does not, there is inefficient standardisation. However, with competitive upgrades, it would be a Pareto improvement for early adopters to use the competitive upgrade to take advantage of the high rate of technological progress. This is also Firm A's profit maximising strategy because increased willingness to pay of early adopters for the new version of Brand A, as well as the increased willingness to pay for network benefit by all consumers, is larger than the cost of offering a competitive upgrade.

In Figure 14, the cost of switching is now less than $4n$ and the cases of inefficient standardisation and inefficient fragmentation completely disappear. Inefficient fragmentation, labelled as area 'c', occurs for higher values of Δ_1 relative to $|\Delta_2|$ where there is a lower rate of technological progress and a greater superiority of Brand B in the first period. In the case without competitive upgrades, the market outcome is BA when the socially optimal outcome calls for BB because Δ_1 is larger and early adopters start with Brand B. Late adopters do not recognise their effect on the early adopters' network benefit and choose Brand A. With competitive upgrades, this situation is replaced with an efficient BCA outcome. In this case, the switching cost is low enough such that it would be a Pareto improvement for early adopters to switch to Brand A using the competitive upgrade if they had already started with Brand B. From a market perspective, the switching cost is low enough such that Firm A's strategy of BCA will yield more profit than strategy BA.

Therefore, in Figure 14, outcome BCA dominates BA from a welfare perspective because if early adopters start with Brand B, the switching cost is low enough that there will be a net benefit to standardising on the *ex post* superior technology. From the market outcome perspective, outcome BCA is also the profit maximising strategy in this parameter range because the consumers' willingness to pay for standardising on Brand A can be captured by the firm. Therefore, for values of θ less than $4n$, inefficient standardisation and inefficient fragmentation are replaced by an efficient BCA outcome.

Also effected by competitive upgrades in Figure 14 is the inefficiency of incorrect standardisation, or area 'a'. This inefficiency occurs for low rates of technological progress because Firm A's second-mover advantage allows it to profit from strategy AUA even though consumers would be better off by standardising on Brand B. Because the value to consumers of standardising on Brand A is small in this case, the switching cost must also be small to 'reach' this inefficiency. However, the incidence of this inefficiency shrinks for exactly the same reason as it did for inefficient fragmentation. As θ decreases, the market outcome AUA and the socially optimal outcome BB are replaced by an efficient BCA outcome. This is evident in Figure 11, where the incidence of incorrect standardisation is at its smallest. In fact, for a switching cost approaching zero, this inefficiency will completely disappear because both the socially optimal outcome and the market outcome converge to BCA.

Competitive upgrades also create two new inefficiencies that are actually variants of two of the Katz and Shapiro (1986) inefficiencies. First, for values of θ greater than $4n$, competitive upgrades create an inefficiency similar to inefficient standardisation. This is labelled as area 'e' on Figure 15 and is called *delayed* inefficient standardisation. In this area, the socially optimal boundary between BA and BCA, is $|\Delta_2| = \theta - 2n$, but the market boundary is $|\Delta_2| = \theta - 3n$. The width of area 'e', where the market outcome is BCA and the socially optimal outcome is BA, is equal to n. This difference is equal to the network benefit reflects the extra profit that Firm A can make from strategy BCA because the market standardises. Because the switching cost is very large, early adopters must be compensated a great deal for switching to Brand A. In fact, Lemma 17 states that when $|\Delta_2|$ is less than $\theta - n$, as it is in area 'e', the price of the competitive upgrade is negative. Under such a situation, Firm A must be extracting even greater surplus from late adopters than it would under strategy BA. In effect, Firm A is extracting surplus from late adopters to subsidise the early adopters' switch to Brand A. This is very similar to Katz and Shapiro's second-mover advantage (1986) with the only difference being the fact that the transfer takes place within the second period, not between periods.

In Figure 14, where the cost of switching is less than $4n$, the inefficiency of delayed inefficient standardisation no longer exists. This is again due to the fact that the switching cost is small enough that outcome BA is neither socially optimal nor the most profitable for Firm A. Therefore, delayed inefficient standardisation is replaced by an efficient BCA outcome.

Instead of delayed inefficient standardisation, competitive upgrades cause a different inefficiency in Figure 14. This new inefficiency, called *delayed* incorrect standardisation, occurs when the market outcome is BCA, but the socially optimal outcome dictates BB. This is labelled as area 'd'[29] and occurs for exactly the same reason as in the case of delayed inefficient standardisation; the only difference between the two cases is that the switching cost is now small enough relative to the network benefit to make standardisation on Brand B socially optimal.

Also of interest is the fact that, provided that the switching cost is greater than $3n$, as it is in Figures 14 and 15, if the outcome is delayed inefficient standardisation, the competitive upgrade price is below cost[30]. However, it should be noted that a below cost competitive upgrade price does not necessarily mean there is inefficiency. For Figures 11 through 15, this relationship between a below cost competitive upgrade price and inefficiency does not continue at all.

As θ decreases, as it does in Figures 12 and 13, the cost of learning a new technology is smaller, and the socially optimal outcome as well as the market outcome becomes BCA. Another difference from Figure 14 is that area 'd' now occurs for values of $|\Delta_2|$ less than n, where it is established that consumers will always standardise in the market outcome. In Chapter 4, the case without competitive upgrades, this meant that once early adopters started using Brand B, it was Firm A's profit maximising strategy to

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29 Delayed inefficient standardisation is also labelled as 'f' and 'g' in cases where the inefficiency overlaps with other areas.

30 See Lemma 17 for a definition of the competitive upgrade price.

allow the market to standardise on Brand B. However, in Chapter 5, once early adopters start using Brand B, the competitive upgrade allows Firm A to capture the entire market when it otherwise would have lost the competition for both consumer groups. This permits delayed incorrect standardisation to take place when, without competitive upgrades, the outcome would have been efficient[31].

Finally, in Figure 11 the incidence of delayed incorrect standardisation is smallest. As before, this is due to the fact that as the cost of switching decreases, outcome BCA becomes more profitable to Firm A and more preferred from a welfare perspective. In fact, for a switching cost approaching zero, this inefficiency will completely disappear because both the socially optimal outcome and the market outcome both converge to BCA. Firm A no longer needs to subsidise the early adopters for switching brands because switching between the two is costless. Thus, there is no private transfer of profits from late adopters to early adopters.

The intuition behind these results is simple. Allowing consumers to switch allows for more flexibility in the market outcome. Consumers and firms react more appropriately to emerging technologies by allowing the product life of the established

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[31] Once the switching cost is below $2n$, as it is in Figure 12, Firm A no longer needs to price the competitive upgrade below cost to get early adopters to switch. However, Firm A is still compensating them for switching by charging them a lower price than they would receive if they had not already invested their time in learning how to use Brand B. See Lemma 17 for the pricing of the competitive upgrade.

technology to run its course. It should also be noted that competitive upgrades cause a net reduction in cases where early adopters purchase Brand A in the first period instead of in the second period. Choi's (1996) result, that the introduction of converters increased the instances of this phenomenon, is not seen in this model because competitive upgrades allow the freedom of second period entry for the emerging technology.

7 CONCLUSION

The problem presented in this paper is one of modifying the existing literature on network externalities to more accurately describe the computer software industry. The network externality literature applies to the computer software industry because, all other things equal, consumers prefer to be part of a network of fellow consumers who use the same product. When consumers derive value from the software if other consumers use it, the addition of one more user will not only benefit the individual, but everyone else that uses the same program. The individual does not account for this, so the societal benefit of her purchase is much greater than her own private benefit. Therefore, there is significant potential for market failure because not enough people will buy into the network in order to maximise societal welfare.

Because of network externalities, the computer software market can be prone to 'tipping' in favour of one product. This is especially true for applications such as word processors and spreadsheets where, due to the small quality differences between the competing products, there is little room for a 'niche' market. Therefore, early stages of competition will be fierce as firms bid for future monopoly profits by doing things to increase the size of the installed base and influence consumers' expectations of both future quality and network size. Microsoft Corporation could be accused of using such a strategy by distributing free copies of its Internet browser and allowing ordinary consumers to freely use copies of software applications still in the testing phase (known as "Beta" versions). The model presented in this paper could interpret this as the first period version of Brand A.

Upgrades, and particularly competitive upgrades, also influence expectations about installed base since they bridge the gap between an obsolete (but still functional) technology and the newest technology. Without upgrades, adoption of the new technology may be slowed because users of the older technology value the improvement less than new consumers value it. If users of the old version still derive some stand-alone benefit from the product, they will require a discount to join the new consumers in adopting the new technology.

This paper shows that competitive upgrades may generate beneficial welfare effects and because they provide another means for the emerging technology to enter the market. This is proved by using a two-stage game that models the transition to a new technology. Within this model, it is assumed that two firms provide inherently incompatible technologies. The first firm provides an established technology that is mature and does not evolve. The other firm provides a technology which is widely recognised to be superior in the future, but is inferior to the established technology at present. Two generations of homogenous consumers purchase these technologies; the early adopters enter the market in the first period and either choose to purchase the established or emerging technology, or wait until the second period when the late adopters enter the market. Both generations of consumers value quality but will choose the inferior product if it provides a sufficient network benefit.

For many parameter values, the resulting market equilibrium shows increased instances of standardising on the *ex post* superior technology, conforming with what the socially optimal outcome requires. This is because the firm supplying the *ex post* superior technology has two options available to bring about its dominance: strategic pricing in the first period and competitive upgrades in the second period. For low rates of technological progress and/or high values of the switching cost, it will choose the strategic pricing strategy. The firm will commit profits that it extracts from late adopters in the second period to subsidise competition in the first period, when it does not have the advantage. By charging a price above cost for late adopters and a price below cost for early adopters, it is compensating early adopters for the positive effects they will have on the late adopters' network benefit. This partially internalises the externality and increases the instances of standardisation.

For high rates of technological progress and/or low switching costs, the firm is most likely to wait until the second period and offer a competitive upgrade to the early adopters who use the established technology. Offering the competitive upgrade in the second period benefits the firm because for high rates of technological progress or low switching costs, it does not have to compete in the first period with an inferior product. Additionally, by offering a competitive upgrade, it is doing something very similar to the strategic pricing case. By getting the early adopters to switch brands, there are positive effects they will have on the late adopters' network benefit. The firm can appropriate some of this surplus to subsidise the offering of the competitive upgrade. This partially internalises the externality and increases the instances of standardisation. The competitive upgrade also benefits the consumer since, she can use the most up-to-date product in each period. Thus, in many cases, competitive upgrades enhance welfare because both the market outcome and the socially optimal outcome are the same.

There are also possible extensions to this model, two of which will be discussed here. First, the compatibility of Firm A's new product with its older version (γ) could be made to be endogenous. Intuitively, this compatibility parameter has some effect on obsolescence, so it would seem that Firm A would have incentive to manipulate γ . However, as the model shows, the parameter γ has no effect on equilibrium[32]. When

[32] To confirm this, see Tables 2 through 6.

early adopters start with Brand A, it is the total price ($p_{1a} + p^{u}_{2a}$) that is important to forward-looking consumers. If p^{u}_{2a}, a function of γ, is raised by the firm, it will only have to lower p_{1a} to keep early adopters purchasing in the first place. Therefore, for the parameter γ to have any effects on the results, the model would have to be adapted to incorporate imperfect information to allow the rate of technological progress to 'fool' consumers. This is touched upon in Choi (1996) and reviewed in Section 2.2.2.

A second possible modification is to make the second period quality difference endogenous through expenditures on research and development. This would serve to endogenise δ_{2a}. As proven in the existing model, Firm A would benefit from a high value of Δ_2 because this would mean that Brand B becomes less competitive. Such a modification can be easily grafted into this model because it already derives all possible profit outcomes for Firm A as a function of δ_{2a}. To find the equilibrium in this case, one would only need to maximise an objective function with respect to R&D costs as they effect δ_{2a}.

Thus, the model presented in this paper is very useful as it gives intuitive results in terms of a few simple variables such as switching costs, network benefits, and quality advantages. Finally, the model can also be adapted to answer an entirely new set of questions.

BIBLIOGRAPHY

Bagnoli, Mark, Stephen W. Salant, and Joseph E. Swirzbinski. "Durable-Goods Monopoly with Discrete Demand." Journal of Political Economy 97 (1989): 1459-1478.

Baseman, K., F. Warren-Boulton, and G. Woroch. "Microsoft Plays Hard-ball: The Use of Exclusionary Pricing and Technical Incompatibility to Maintain Monopoly Power in Markets for Operating System Software." The Antitrust Bulletin 40 (1995): 265-315.

Bensaid, Bernard and Jean-Philippe Lesne. "Dynamic Monopoly Pricing with Network Externalities." International Journal of Industrial Organisation 14 (1996): 837-855.

Blair, Roger D. and Amanda K. Esquibel. "The Microsoft Muddle: a caveat." The Antitrust Bulletin 40 (1995a): 257-315.

Blair, Roger D. and Amanda K. Esquibel. "Some remarks on monopoly leveraging." The Antitrust Bulletin 40 (1995b): 371-396.

Bulow, Jeremy I. "Durable-Goods Monopolists." Journal of Political Economy 90 (1982): 314-332.

Bulow, Jeremy I. "An Economic Theory of Planned Obsolescence." The Quarterly Journal of Economics 101 (1986): 729-749.

Choi, Jay P. "Network Externality, Compatibility Choice, and Planned Obsolescence." The Journal of Industrial Economics 42 (1994a): 167-182.

Choi, Jay P. "Irreversible Choice of Uncertain Technologies with Network Externalities." RAND Journal of Economics 25 (1994b): 382-401.

Choi, Jay P. "Do Converters Facilitate the Transition to a New Incompatible Technology? A Dynamic Analysis of Converters." International Journal of Industrial Organisation 14 (1996a): 825-835.

Choi, Jay P. "Standardisation and Experimentation: Ex ante vs. *Ex post* Standardisation." European Journal of Political Economy 12 (1996b): 273-290.

Choi, Jay P. and Marcel Thum. "Market Structure and the Timing of Technology Adoption with Network Externalities." European Economic Review 42 (1998): 225-244.

Chou, Chien-fu and Oz Shy. "Do Consumers Gain or Lose When More People Buy the Same Brand." European Journal of Political Economy 12 (1996): 309-330.

Church, Jeffrey and Neil Gandal. "Strategic Entry Deterrence: Complementary Products as Installed Base." European Journal of Political Economy 12 (1996): 331-354.

Church, Jeffrey and Roger Ware. "Network Industries, Intellectual Property Rights and Competition Policy." Competition Policy and Intellectual Property Rights in the Knowledge-Based Economy. Anderson, Robert D., and Nancy T., Gallini eds. Calgary: University of Calgary Press, 1998. 9. 227-285.

Coase, R. "Durability and Monopoly." Journal of Law and Economics 15 (1972): 143-149.

David, P. A. "Clio and the Economics of QWERTY." The American Economic Review 75 (1985): 332-336.

de Palma, Andre and Luc Leruth. "Variable Willingness to Pay for Network Externalities with Strategic Standardisation Decisions." European Journal of Political Economy 12 (1996): 235-251.

Dhebar, Anirudh. "Durable-Goods Monopolists, Rational Consumers, and Improving Products." Marketing Science 13 (1994): 100-120.

Economides, Nicholas. "Network Externalities, Complementarities, and Invitations to Enter." European Journal of Political Economy 12 (1996): 211-233.

Farrell, Joseph and Garth Saloner. "Standardisation, Compatibility, and Innovation." RAND Journal of Economics 16 (1985): 70-83.

Farrell, Joseph and Garth Saloner. "Installed Base and Compatibility: Innovation, Product Preannouncements, and Predation." The American Economic Review 76 (1986a): 940-955.

Farrell, Joseph and Garth Saloner. "Economic Issues in Standardisation." Economics Letters 20 (1986b): 71-74.

Farrell, Joseph and Carl Shapiro. "Dynamic Competition with Switching Costs." RAND Journal of Economics 19 (1988): 123-137.

Farrell, Joseph and Garth Saloner. "Converters, Compatibility, and the Control of Interfaces." The Journal of Industrial Economics 15 (1992): 9-35.

Fudenberg, Drew and Jean Tirole. "Upgrades, Trade-ins, and Buybacks." RAND Journal of Economics 29 (1998): 235-258.

Gandal, Neil. "Hedonic Price Indexes for Spreadsheets and an Empirical Test for Network Externalities." RAND Journal of Economics 25 (1994): 160-170.

Grindley, Peter. Standards, Strategy, and Policy. Oxford: Oxford University Press, 1995.

Gul, Frank, Hugo Sonnenschein, and Robert Wilson. "Foundations of Dynamic Monopoly and the Coase Conjecture." Journal of Economic Theory 39 (1986): 155-190.

Hotelling, H. "Stability in Competition." Economic Journal 39 (1929): 41-57.

Jones, Philip and John Hudson. "Standardisation and the Costs of Assessing Quality." European Journal of Political Economy 12 (1996): 355-361.

Karp, Larry S. and Jeffrey M. Perloff. "The Optimal Suppression of a Low-Cost Technology by a Durable-Good Monopoly." RAND Journal of Economics 27 (1996): 346-364.

Katz, Michael L. and Carl Shapiro. "Network Externalities, Competition, and Compatibility." The American Economic Review 75 (1985): 424-440.

Katz, Michael L. and Carl Shapiro. "Technology Adoption in the Presence of Network Externalities." Journal of Political Economy 94 (1986): 822-841.

Katz, Michael L. and Carl Shapiro. "Systems Competition and Network Effects." Journal of Economic Perspectives 8 (1998): 93-115.

Lee, In Ho and Jonghwa Lee. "A Theory of Economic Obsolescence." International Journal of Industrial Organisation 46 (1998): 383-401.

Liebowitz, S. J. and Stephen E. Margolis. "The Fable of the Keys." Journal of Law and Economics 33 (1990): 1-26.

Liebowitz, S. J. and Stephen E. Margolis. "Network Externality: An Uncommon Tragedy." Journal of Economic Perspectives 8 (1994): 133-150.

Lopatka, John E. and William H. Page. "Microsoft, monopolisation, and network externalities: some uses and abuses of economic theory in antitrust decision making." The Antitrust Bulletin 40 (1995): 317-369.

Matutes, Carmen and Pierre Regibeau. "A Selective Review of the Economics of Standardisation, Entry Deterrence, Technological Progress and International Competition." European Journal of Political Economy 12 (1996): 183-209.

Shy, Oz. "Technology Revolutions in the Presence of Network Externalities." International Journal of Industrial Organisation 14 (1996): 785-800.

Thum, Marcel. "Network Externalities, Technological Progress, and the Competition of Market Contracts." International Journal of Industrial Organisation 12 (1994): 269-289.

Tirole, Jean. The Theory of Industrial Organisation. 8th ed. Cambridge: MIT Press, 1995.

Waldman, Michael. "A New Perspective on Planned Obsolescence." The Quarterly Journal of Economics 108 (1993): 273-283.

Waldman, Michael. "Planned Obsolescence and the R&D Decision." RAND Journal of Economics 27 (1996): 583-595.

Waldman, Michael. "Eliminating the Market for Second-hand Goods: An Alternative Explanation for Leasing." Journal of Law and Economics 40 (1998): 61-92.