PIRACY OF DIGITAL PRODUCTS:
A CRITICAL REVIEW OF THE ECONOMICS
LITERATURE

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Abstract

Digital products have the property that they can be copied almost costlessly. This makes them candidates for non-commercial copying by final consumers. Because the copy of a copy typically does not deteriorate in quality, copying products can become a wide-spread phenomenon – this can be illustrated by the surge of file-sharing networks. In this paper we provide a critical overview of the literature that addresses the economic consequences of end-user copying. We conclude that some models with network effects are well-suited for the analysis of software copying while other models incorporating the feature that copies provide information about the originals may be useful for the analysis of digital music copying.

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1. Introduction

With the rise of the computer and the internet, an increasing number of digital products and services have been copied and distributed most of the time without the authorization of legal owners. They involve books, software, music and video files. This trend has become a concern for both product manufacturers and policy makers. A recent illustration are the legal actions by record companies against file-sharing technologies and their users, backed up by the reinforcement of the copyright law stated in the Digital Millenium Copyright Act. The main argument of the record companies is the huge revenue losses claimed to be due to internet piracy. But in which eonomic environments can such a claim be substantiated? Are there other strategies that copyright owners can use to counter this new form of piracy? And, from a public policy perspective, to which extent are the social interests aligned with the interests of copyright owners?

Before presenting the various arguments and results that can be found in the theoretical literature, it is useful to analyze the characteristics of digital products and how piracy works. Digital products can be compressed without losing much information or quality. Thus, digital copies have a technical quality similar to the original. However, the original digital product is often bundled with other non-digital components such as a printed manual for software and printed booklet (with lyrics, pictures, song and artist information) and CD case for music CDs.

In most cases, digital products also involve interactions. These interactions can be of two different natures: formal interaction for software that require to exchange standardized/formatted information, and social interaction for music and video files about which people like to talk about with their friends. These formal and social interactions imply that there possibly exist network effects in the use of a digital product either as the original or as a copy.

Also, many digital products are complex in the sense that the amount of information required to describe them is large. As a consequence, consumers need to test them in order to correctly value them. In other words, some digital products are experience goods and a copy can be useful in providing information on its characteristics. This feature applies not only to digital products such a musical CDs but also to software with a large number of commands and a large potential number of interactions with other computer components and software, etc.

Non-authorized copying of digital products can be done in two different ways: by borrowing originals from friends and family members or by downloading from the internet. In the former case, networks of friends share the good on a small-scale basis. Then it is possible in some case to indirectly appropriate revenue from sharing activities as we will argue later on. The copying process only requires a storage device such as a hard-drive or a CD Recorder or any portable media device. Information on the characteristics of the copied product is easy and cheap to obtain by word-of-mouth. In the latter case,

monitoring copies from copies is arduous. However, copying using file-sharing technologies provides a lower value than copying directly from friends for several reasons. First, users are spending time looking for and downloading files. Secondly, the digital copy lacks valuable information such as instructions on how to install the software or song lyrics. Finally, the file can be badly compressed or incomplete. Therefore, we can expect consumers to be heterogeneous with respect to the value of the original relative to the copy.

Some theoretical efforts have been made by economists to better understand the consequences of piracy on profits and welfare. This survey exclusively considers end-user copying.[1] It is organized according to different modeling features. In general, it is assumed that there exist differences between the original and its copy and that consumers are heterogeneous (in a way to be defined) between their willingness to pay for the original compared to the copy. In a first set of articles, consumers are perfectly informed about the characteristics of the digital product and the value that they put on it is independent of the decision of other consumers for any given price. In such a setup we elaborate on the possibility to indirectly appropriate rents. In a second set of articles, this value does depend on the decision of other consumers. In other words, there are network externalities. In a third set of articles consumers are not perfectly informed about the characteristics of the product and copying provides information on the value of the product, facilitating the purchasing decision. As we will discuss in a final section, the second set of articles mainly addresses software piracy whereas the third set of articles mainly addresses music piracy.

In the three setups the following two questions are raised:[2]

- Do firms suffer from the existence of copies?
- Does the availability of digital copies increase or decrease welfare?

The answer to the first question is an unambiguous "yes" in the first setup. In the second and third setups, firms may gain when digital copies are available. When firms suffer and consumers gain from copies, the second question has to be studied in detail. On the one hand, the short-term view assumes that a particular set of products exists and asks what are the welfare implications of copying. On the other hand, from a long-term perspective one has to analyze the incentives of a firm to enter the market or innovate and the question becomes: what is the welfare effect of copying on the creation process? Additional questions come to mind: what is the socially optimal level of copyright protection? Do there exist mechanisms (for example taxes on copying) that improve profits and welfare?

The remainder of the review is organized as follows. We look at a selection of articles analyzing issues around digital copies in sections 2 to 5. Section 2 presents the analysis of copying under product differentiation, where we abstract from a number of considerations that are the topic of the remaining sections. Section 3 discusses indirect appropriability, section 4 network effects and section 5 partial consumer information. In section 6 we then discuss the relevance of some of the model ingredients for the analysis of software applications, online games, and digitally compressed music files.

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[1] We do not address for-profit piracy. Recent contributions on this topic include Slive and Bernhardt (1998), Banerjee (2003), and Poddar (2003).

[2] An early, informal exploration of these questions concerning the copying of books and periodicals can be found in Hurt and Schuchman (1966).

2. Product differentiation between original and copy

We consider pirated goods that are digital copies of original files. The original has quality q, the copy may be of lower quality, $q^c \le q$. This means that markets offer two versions of the product: the original and a lower quality product that can be obtained at a given price, which possibly varies across consumers. This price may be zero; it is positive if the pirated good is costly to acquire or if there are expected cost from being detected. The non-authorized copy therefore limits the monopoly power of the supplier of the original. We would therefore expect as a quite general result (without other effects) that the availability of a pirated good either leaves the firm's profits unchanged (this means that piracy is not a real threat) or that it reduces the firm's profits. This is indeed confirmed in a variety of models (see, for instance, Novos and Waldman, 1984, Johnson, 1985, and Belleflamme, 2002). A firm can react to piracy in three different ways: if piracy is not a real threat the firm may not react at all; if it is a threat worth fighting, the firm reduces its price such that all active consumers prefer the original (call this strategy "deter"); otherwise, the firm responds in such a way that some consumers obtain only the pirated good ("accommodate"). Both the deterrence and the accommodation strategy lead to reduced profits.

Changes in profits typically modify incentives to provide quality. In a model in which original and copy have the same quality but in which consumers have heterogeneous copying costs, Novos and Waldman (1984) have shown how lower profits reduce under some assumptions the ex ante incentives to provide quality. Hence, one has the classic trade-off between underprovision and underutilization already pointed out by Arrow (1962). This result is confirmed by Bae and Choi (2003) in a vertical product differentiation model with quality degradation for copies. In a multi-product framework, Johnson (1985) shows how lower profits also reduce the incentives to provide variety. This implies that although a short-term welfare analysis may see piracy in a favorable light, the long-term effects are more likely to be negative.

Strategies in a single-market scenario. We will now look at this argument in more detail. Following Novos and Waldman (1984) a consumer can either purchase the original or copy at a cost $c + z(1 + x)$, where c is the marginal cost of production, x is the extent of copyright protection and z is the additional marginal cost of making a copy, which is heterogeneous across consumers. The value that consumers attach to the product depends on its quality. Because of the heterogeneity in the copying costs, for moderate prices, some consumers prefer the original while others the copy. Clearly, if the firm's price is sufficiently low, copying is unattractive to all consumers. While Novos and Waldman clearly had physical copies in mind, this specification also fits digital products such as software for which users who illegally copy have to spend effort and time downloading, copying, and installing files and incur an additional disutility if they are detected. The monopolist produces a single quality and copies have the same quality as the original. However, the model can be interpreted as if the value of the original relative to the copy is heterogeneous but that the associated disutility of copying is the same for all consumers. That is, the original gives a value which

is the same across consumers, while the copy gives the same value minus $z(1 + x)$. In words, the perceived quality degradation of the copy is heterogeneous.

In this model, the monopolist chooses a quality which is too low compared to the social optimum because the monopolist cannot appropriate all rents from quality improvements. Novos and Waldman then show that an increase in copyright protection leads to an increase in the quality offered by the monopolist provided that the density of z is increasing, i.e. there are relatively more consumers with higher than with lower copying costs. This means that the effect of underprovision favors a strict copyright enforcement. The social loss due to underutilization in their model is the additional cost wasted by consumers who copy since all consumers eventually consume the good (either as the original or the copy). In their model, a stricter copyright protection does not increase the social loss due to underutilization: as the copyright protection increases, some consumers switch from the copy to the original, thus saving the copying cost that is wasteful from a social point of view. See also Bae and Choi (2003).

Chen and Png (2002) point out that other social costs arise if firms spend resources on detection. In their simple setting, there are two groups of consumers: one group never copies (infinite copy costs) and another group has finite copying costs. In each group, consumers have heterogeneous valuations for the good although originals and copies are identical. The expected utility from illegal copying depends on the detection probability. A firm has two possibilities to eliminate copies: it can lower its price or it can spend additional resources in a technology that increases the detection probability. Clearly, from a social point of view, these two strategies have different implications. On the one hand, a lower price unambiguously improves welfare because less effort in copying is needed. On the other hand, increasing the detection probability is wasteful from a social point of view and the surplus of copiers is also reduced.[3]

Another similar set-up to formally investigate the effects of piracy is the Mussa-Rosen model of vertical product differentiation (Mussa and Rosen, 1978). In this framework, the heterogeneity with respect to the copying costs is replaced by heterogeneity with respect to the utility derived from the quality difference between the original and the copy. Consumers have unit demand and make a discrete choice between the original and the copy. Consumers differ in their willingness to pay for the products (the original and the copy). A consumer with a larger taste parameter $\theta > \theta'$ has a higher willingness to pay than consumer θ'. She is also willing to pay more for the original if the alternative is to obtain a copy. Two specifications of the heterogeneity of consumers' valuations dominate the literature:
1. two types (high-value and low-value consumers).
2. a continuum of types; the distribution is then often assumed to be uniform on an interval.

Belleflamme (2002), Yoon (2002), and Bae and Choi (2003) consider a single product monopolist selling to a continuum of heterogeneous consumers. A consumer derives utility $\theta q - p$ for the original, where θ is the consumer's taste parameter, distributed uniformly on the unit interval, q is the quality of the original (which is exogenously given in Yoon, 2002), and p its price. She derives

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[3] Chen and Png then analyze the socially optimal government policy consisting of a tax on copies and recording equipment, subsidies to originals, and penalties in case of copyright violations.

utility $\alpha \, \theta q - c$ for the copy, where $1 - \alpha$ is the factor of quality depreciation and c the copying cost. Suppose that the marginal cost of production is zero. Then pricing in the presence of piracy is the same as pricing against a firm pricing at c a product of quality $\alpha \, q$. Obviously, in this setup the firm's profits decrease with the availability of digital copies.[4]

The total effect of piracy on welfare is positive because the loss in profits (from deterring or accommodating piracy) is overcompensated by an increase in consumer surplus. Lower profits, however, reduce the ex ante incentives to provide the good. Bae and Choi (2003) also show that more originals are sold if copies are available, albeit at a much lower price. In the example of a uniform distribution this can be explained by the fact that the monopolist faces a flatter linear demand function if copies are available (see Bae and Choi, 2003, for details).

Yoon (2002) considers the more elaborate problem in which copyright protection leads to a private cost to consumers. Formally, a consumer's utility takes the form $\alpha \, \theta q - c - x$, where x denotes the consumers' additional cost due to copyright protection (which also constitutes a social cost). Then the monopolist's profits are increasing in x, while consumer surplus is decreasing. Total surplus is initially decreasing in x and then, after reaching its minimum, inversely U-shaped. Yoon then shows that the socially optimal copyright protection should be set such that the monopolist optimally reacts to the threat to copying by deterring copying. The copyrighted product is then fully protected in the sense that copies are driven out of the market. However, the monopolist has to lower its price compared to a situation of "blockaded entry", that is if copying is not feasible. In this sense, copyright is *not* fully protected under the social optimum. Bae and Choi (2003) extend the analysis to the situation in which consumers face a type-dependent cost $\beta \, \theta q$ due to copyright protection. A higher degree of copyright protection reduces the demand for originals. Note that this finding is in contrast to what happens in the previous situation when copyright protection gives rise to a uniform cost x because, with a uniform cost, enacting copyright protection increases the demand for originals. Total surplus unambiguously decreases with the degree of copyright protection.

Takeyama (1997) argues that the loss in profits due to copying may be greater if dynamic effects are taken into account. Consider a two-period model in which there are two types of consumers, one with a high valuation for the good and no propensity to copy (high type) and another type with a low valuation for the good and a strong propensity to copy (low type). Consumers buy up to one unit in the two periods. Takeyama assumes that the monopolist cannot commit to prices, that is, the monopolist suffers from a Coasian commitment problem. Without copying, high type consumers anticipate a lower price in the second period, which is set to make the low type consumers indifferent between buying and not buying. Therefore, the monopolist has to offer a price strictly below the valuation of the high type consumers in the first period so as to satisfy their incentive constraint. When copying is possible, the monopolist has to lower the

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[4] Although profits are reduced in the monopoly setting, committing not to enforce copyright protection may be a profitable strategy in a market with potential entry as it may serve as an entry deterrent. The reason is that an entrant suffers if the incumbent does not enforce copyright protection.

second period price to make the low type indifferent between buying and copying. The associated reduction in profits is equivalent to profit reduction in an atemporal model. However, the lower second-period price affects the incentive constraint of the high type consumers so that the monopolist also has to lower the first-period price. This also reduces first-period profits.

While the dynamic problem typically amplifies the negative effect of piracy on profits due to copying, Takeyama also notes that copying can increase profits in some cases. Indeed, if the monopolist cannot avoid copying in the second period without making losses in that period, that is, if the marginal costs of production and selling of the good are above the private copying cost of low type consumers, then, the availability of copies in the second period serves as a commitment not to offer the good in the second period. As a consequence, in the first period, the participation constraint and not the incentive constraint of the high type becomes binding. In other words, the monopolist can extract the full surplus from high type consumers.

In a related paper, Alvisi, Argentesi and Carbonara (2002) analyze the incentives of a firm facing piracy to offer a downgraded version.[5] Absent piracy, the set-up is a Mussa-Rosen model, which is specified such that only a single quality is offered by the monopolist. Consider now the introduction of copies. Copies are assumed to have the same quality as originals. To make a consumer buy the original, its price has to be less or equal to the copying cost of the consumer, c. Clearly, if these copying costs only represent physical reproduction costs a firm can only make positive profits if there are increasing returns to scale in production. However, including heterogeneous opportunity costs for the consumers (as discussed above) allow for positive profits even without increasing returns in production. Consumers belong to two different classes: one class of consumers below a certain parameter value θ are assumed to have low copying costs, c_L, and the other class above that value are assumed to have a high copying costs, c_H. This means that a high quality product can be offered at a higher price to consumers with a high valuation of quality. The authors then show that the optimal response of the monopolist to piracy may be to offer two qualities: the lower quality attracts low value consumers and the high quality attracts high value consumers. This means that the monopolist effectively discriminates between those consumers with a high copying cost and those with a low copying cost. The optimal strategy is characterized by the fact that prices are below copying costs for each consumer class and that consumers with low copying costs also do not have an incentive to copy the high-quality good.

Multi-market scenario. Similar in spirit to Johnson (1985), Belleflamme (2002) extends his analysis to a multi-market framework in which each firm offers a single product. As long as demands are independent, all results from the single-market scenario trivially carry over. With sufficiently heterogeneous fixed costs some firms do not enter the market. For a particular uniform distribution of these fixed costs across firms, Belleflamme then shows that the existence of copies reduces welfare if copies are good substitutes for originals and that it increases welfare if they are bad substitutes.

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[5] A number of articles have looked at the incentives to provide downgraded goods without piracy but with network effects. These include Hahn (2001a,b) and Csorba (2002).

Belleflamme (2003) considers an environment in which demand is interdependent in the presence of copying because a consumer's copying technology exhibits increasing returns to scale. This is typically the case if a consumer incurs a high initial fixed cost to be able to copy, for example by buying a CD burner or by breaking the "moral barrier" to illegal copying. If the consumers' average cost of copying the chosen set of goods is sufficiently high, a multi-product monopolist will either set the unconstrained monopoly price or lower its price so as to avoid copying. In contrast, if each single information good is provided by one firm, these firms might have to accept copying as an industry phenomenon. Namely, for certain configuration each firm tolerates copying and sets a high price to extract a high margin from those consumer who buy originals.

Broad-based versus targeted copyright enforcement. The copying cost c plays an important role in determining whether original and pirated good are good or bad substitutes. This cost is partly determined by the copyright enforcement policy of the copyright owner (as seen in Novos and Waldman, 1984, and Yoon, 2002). A broad-based enforcement policy affects all consumers in the same way. As an alternative, a targeted enforcement policy concentrates on high value consumers. Harbaugh and Khemka (2001) have analyzed the effects of such a targeted enforcement policy in a vertical differentiation model with a continuum of consumer types. Compared to the same level of broad-based enforcements, a targeted enforcement policy makes copying relatively more costly for high-value buyers than for low-value buyers. There is thus a wedge between those two groups – the group sizes are determined by the scope of the enforcement policy. The main result of Harbaugh and Khemka (2001) is that the optimal monopoly price with targeted enforcement may be above the monopoly price without piracy, p^M. The reason is that with targeted enforcement and positive enforcement costs the monopolist may not want to apply enforcement up to the level of the demand that would be served by the monopolist without piracy but may want to choose a more limited scope. Then, if enforcement is sufficiently effective to deter the targeted consumer segment from copying, prices are above p^M. This implies that profits and the surplus of targeted consumers are reduced compared to a world without piracy. At the profit maximizing scope of enforcement policy, consumer surplus may increase with enforcement. Then the private incentives to enforce copyright may be insufficient from a social perspective with targeted enforcement.

We note that targeted enforcement can be viewed as a costly device to create two types of consumers: those who are willing to pay a high premium on originals and those who are essentially not willing to pay for originals. This means that a model with a continuum of types and targeted enforcement becomes a model with essentially two types.

3. Indirect appropriation

Although the purchaser of copyrighted work may legally or illegally copy the original, the copyright owner may partially or even fully appropriate the benefits from copying. The issue of indirect appropriation already arises in the case of photocopies of books and other printed material, see Liebowitz (1985). However, it is difficult to indirectly appropriate revenues from copies when one can not

exactly assess the amount of copying that will be done from a single original. Indirect appropriation either requires a homogenous population of buyers of the original or effective price-discrimination devices. Suppose that it is possible to price-discriminate as a function of the potential number of copies that will be made. Then the copyright owner can charge a higher price to those who are expected to copy more. Of course, it must be possible to prevent arbitrage; in the case of a library, this is possible since libraries are easy to identify. Note that indirect appropriation can partially explain the shift from books (weak complement with photocopiers) to journals (strong complements) in the academic profession. This change in demand due to copying is referred to by Liebowitz (1985) as the exposure effect.[6]

Besen and Kirby (1989) note that the advantage of direct versus indirect appropriation depends on the technology of copying and the substitutability between originals and their copies. They propose a model with small-scale copying to show that direct appropriability arises when the marginal cost of copying is constant and indirect appropriability when the marginal cost is increasing in the number of copies. Strong substitutability between originals and copies and increasing marginal cost of copying lead to as situation of clubs who share the cost of the original among its members (copiers).[7] Three cases are considered.

Case 1: the marginal cost of copying is constant but greater than the marginal cost of producing the original; copies and original are imperfect substitutes. In this case, copiers pay the marginal cost of reproduction so that the price of a copy is equal to its marginal cost. In other words, there is direct appropriability: producers can only capture the net surplus from selling the originals.

Case 2: the marginal cost of copying is increasing and originals and copies are perfect substitutes; copies can only be made from the original,[8] and members of the club only consume one unit. Copying leads to an increase of the price of the original and there is indirect appropriation. The analysis is similar to the pricing of a club membership. The fixed cost of the club is the price of the original. Because the marginal cost of copying is increasing, the average cost curve is U-shaped. Competition between clubs drives membership fees down to the minimum average cost. This determines the optimal size of the club. Consider now the log difference in profits when copying is possible and when it is not. Besen and Kirby show with numerical methods that this difference is increasing in the marginal cost of producing the original and becomes positive for some values. Thus the firm may increase profits by indirectly appropriating revenues from the copies.

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[6] Liebowitz tests for indirect appropriability by analyzing the change in the relative price of an economic journal charged to institutions and individuals between 1959 and 1982 as a function of its usage (measured by citations). After controlling for journal age and commercial journals, Liebowitz finds a positive relation between the usage and the relative price of copyrighted good. Also, price discrimination increased after the introduction of photocopy machines and demand for material that is easy to copy (such as a journal) had increased compared to other materials (such as books that are more difficult to copy), illustrating the exposure effect.
[7] Besen and Kirby (1989) point out that their mechanism is related to the literature about a monopolist facing a second-hand market.
[8] If copies could be made from copies at the same cost (and quality) as from the original then the analysis of case 1 would apply.

Case 3: the marginal cost of copying is increasing; copies and originals are not perfect substitutes. The club organizer is now the consumer who has the highest surplus from consuming the original rather than the copy. This consumer sells the copy to the other members. Because of the positive surplus of the club organizer and of the copiers, the producer of original work can again indirectly appropriate revenues from the copies.

Bakos, Brynjolfsson, and Lichtman (1999) present an argument based on bundling why the existence of clubs may increase the copyright owner's profits. Suppose that consumers belong to clubs that correspond to non-overlapping and exogenous network of friends. The valuation of the club is the sum of valuations of each club member. Bakos et al. highlight two opposing effects of sharing.

The first positive effect of sharing is referred to as the "aggregation effect" and is due to the fact that consumers who team up together reduce the variance of the distribution of consumers' valuation from the point of view of the producer under the strong assumptions that all valuations are independent (and identically distributed) and all teams have the same size. The reason is that as the number of consumers sharing the good increases, the likelihood that the team will value the product at an average value increases — in the limit, this can be seen by applying a Central Limit Theorem. Thus the firm can extract more surplus from larger clubs with a mean (aggregate) valuation. To present the argument in a simple way, suppose that there are two consumers, each with valuation uniformly and independently distributed on the interval $(0, 1)$. With two clubs of size 1 with valuation x distributed according to $F_1(x) = U(0, 1)$, the expected demand at price p is $d_1(p) = 2 (1-F_1(p)) = 2 (1-p)$ by the definition of the cumulative distribution function of the uniform distribution. The profit is thus $\pi_1 = 2 (1-p) p$ and the optimal price is $p = 1/2$ with corresponding profits $\pi_1 = 1/2$. When there is one club of size 2, the distribution of valuation of the club is simply the distribution of the sum of the valuation of the team members and has probability distribution $F_2(x) = x^2/2$ if $x \leq 1$ and $F_2(x) = 1/2 + 2(x-1) - 1/2 (x^2-1)$ if $x > 1$. Thus the expected demand at price p for the team is $d_2(p) = 1 - F_2(p)$. Suppose $p \leq 1$. Then expected demand is $d_2 = 1-p^2/2$ and profit is $\pi_2 = (1-p^2/2) p$. The first order condition of this concave program yields $p = \sqrt{(2/3)}$ and profits are $\pi_2 = (2/3)^{(3/2)} \cong .54 > .5 = \pi_1$. Thus profit increases with a club of size 2 compared to two clubs of size 1 (regardless of the optimal price set when $p > 1$).

There may however exist a second negative effect: introducing positive correlation between valuations of club members and different club sizes leads to a negative "club diversity" effect due to the flattening of the distribution of the club valuations. The net effect of sharing then depends on whether the aggregation or the club diversity effect dominates.

The analysis of Bakos, Brynjolfsson, and Lichtman (1999) presumes that clubs are able to extract all surplus from its members. However, unequal contributions by the members of a club may not satisfy the incentive compatibility constraints of some of the members. In contrast, Varian (2000) analyzes the profitability of a monopolist selling to clubs where clubs do not price discriminate among their members. In this case it may be more profitable to sell to clubs rather than to their members directly because of a cost effect. To be precise, suppose that it is cheaper to sell originals to clubs, which have their own system of giving their

club members access to the good, than reaching out to the members directly. Then the associated sharing and copying agreements within a club are profit enhancing.

We note that the marginal production costs of a digital product are, by definition, negligible. Therefore, based on production costs only, it cannot be profitable to sell information goods through clubs. However, the definition of costs may be too narrow because marketing and distribution costs should be included. In this case, private copying (done within clubs) may be profit enhancing for the monopoly supplier of an information good. This may, for example, explain the practice of site licenses for software.[9]

4. Network effects and piracy

In the presence of network effects there may exist private and social benefits from not enforcing copyright protection. This argument has been made in the case of software piracy but also applies to some extent to other digital products. Network effects for software are likely to be partly direct and partly indirect. The usefulness of a software often directly increases with the number of users because (in case of incompatibility or only partial compatibility with other products) a user can more easily exchange files generated with that software; it typically indirectly increases with the number of users because more complementary products and services are offered (due to increasing returns).

One can also make the case for network effects for copying books and other written material and music. Copying books and music increases the number of people who are knowledgeable about the product. This may for example increase the social prestige of a legal owner in a social gathering. Direct network effects are also present if copying is done through a file-sharing system such as Kazaa where a larger number of downloads from an upload leads to a better user's priority rating.

Network effects under monopoly. We first review a number of studies in a monopoly setting. These papers reject the view that without indirect appropriation copying necessarily reduces the monopolist's profits. Conner and Rumelt (1991) propose a model in which a consumer's willingness to pay increases in the number of users. Clearly, piracy can increase the total number of users and therefore under some circumstances indirectly lead to higher private benefits (of the software developer). Although, a pirated product is "sold" by definition at a price of zero, the willingness to pay for the product increases. This increase can be partially appropriated by the software developer. Conner and Rumelt (1991) present a linear demand model with heterogeneous gains from buying the original instead of using a pirated product (the specification is assumed rather than derived from principals; for a specification which generates such linear demand see Shy and Thisse, 1999). In this specification they show that (*i*) piracy can increase or decrease the optimal price charged by the software developer and (*ii*) piracy can increase or decrease profits. Copyright protection may decrease the total number of users. For certain parameter configurations, price and profits move in the same direction, for others they move in opposite directions.

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[9] Varian (2000) also shows that the use of site licenses and similar agreements may be used as a price discrimination device if there are different types of consumers.

Takeyama (1994) provides a similar analysis in which market demand is explicitly derived from individual behavior. Contrary to the previous model, in her model with full enforcement of copyright protection the optimal strategy of a monopolist may involve selling to all consumers, i.e., also to those consumers who would copy the product if the enforcement was not in place. The profit-maximizing strategy given no enforcement may then give higher profits than the profit-maximizing strategy given full enforcement.

Taking a closer look at her model, there exist two types of users: high- and low-value users. Each user only receives a share α of the net utility associated with the original when using an illegal copy. This utility depends positively on the number of users. Therefore, her model has two distinctive features. First, the disutility from using the pirated rather than the original version is higher for high-value than for low-value users. In other words, the pirated and the original good are closer substitutes for low-value users than for high-value users – this condition is necessary to separate types. Secondly, the network effect is more pronounced for the original than for the copy.

Under certain conditions the optimal uniform pricing strategy is to set a price such that all users buy the product when piracy is impossible. With this strategy, network effects are fully exploited. However, when the firm faces piracy, low-value users do not purchase when the price is too high but still use the product. This makes it possible to charge a higher price to high-value users because network effects are fully exploited. Under certain parameter configuration, profits without enforcement are higher than profits with full enforcement of copyright protection. The reason is that copying with network externalities is a device which allows to milk high-value consumers without foregoing network effects.

A simple example illustrates this point. Suppose that there is a mass 1 of high value users and similarly a mass 1 of low value users. High value consumers have an indirect utility $N - p$ when purchasing the product and αN when obtaining a pirated copy ($0 < \alpha < 1$), where N is the consumer mass with a copy or the original. Low value consumers have an indirect utility $\varepsilon N - p$ when purchasing the product and $\alpha \varepsilon N$ when obtaining a pirated copy ($0 < \varepsilon < 1$). When copyright protection is fully enforced, the monopolist sets its uniform price either equal to 2ε if all consumers are served or 1 if only high-value consumers are served. Associated profits are 4ε and 1, respectively. Hence if $\varepsilon < 1/4$ it is optimal to serve only high-value users, while if $\varepsilon > 1/4$ it is optimal to serve all potential users. With piracy it may be optimal to sell the good only to high value users. The highest price to achieve this is $2(1-\alpha)$. Associated profits are $2(1-\alpha)$. This is optimal if $2(1-\alpha) > 4(1-\alpha)\varepsilon$ which is equivalent to $\varepsilon < 1/2$. Hence if $1/2 > \varepsilon > 1/4$ it is optimal to serve high value users with piracy and all potential users when copyright protection is fully enforced. Profits are higher in the former regime if $(1-\alpha) > 2\varepsilon$. This means that the original must be sufficiently superior to the pirated version.

Similarly, Gayer and Shy (2003) consider a monopoly model in which original and copy are horizontally differentiated and in which the original may give higher fixed utility and stronger network effects. If network effects for the

original are sufficiently strong, the monopolist's profits are larger with the availability of copies.[10]

Belleflamme (2002) extends his basic model (see above) to allow for (weak) network effects. Utilities are $(\theta + \mu N) q - p$ for the original and $(\theta + \mu N) \alpha q - c$ for the copy. Note the difference to Takeyama (1994) where the type-dependent utility depends on the network size. Here only the fixed utility depends on the network size (as in Conner and Rummelt, 1991). Another difference is the assumption on the heterogeneity of consumers' valuations: Takeyama assumes that there are two types of consumer whereas Belleflamme considers that consumers are uniformly distributed on a certain range. Belleflamme then shows that with a limited strength of the network effect piracy always reduces profits. This is in contrast to the more striking findings by Takeyama (1994) and Gayer and Shy (2003).

Takeyama (1994) also obtains some welfare conclusions. She shows that copying can lead to a Pareto improvement compared to the setting in which copying is not possible. This occurs when the monopolist only sells to high value consumers with and without copyright enforcement and when profits increase with copying.

Gayer and Shy (2002) analyze the effect of hardware taxation on the demand for software in a model with network effects. They postulate that all active consumers have to buy the hardware. As can be expected, a tax on hardware reduces copying but it reduces demand for the software in general because a higher price for hardware makes the bundle consisting of hardware and software more expensive. Nevertheless, if the software producer receives the proceeds from the hardware tax, its profits may increase if the tax goes up. They show that the profit-maximizing tax-rate is below the tax rate that eliminates piracy.

Strategic interaction. Shy and Thisse (1999) extend the analysis by Conner and Rumelt (1991) and Takeyama (1994) to a duopoly framework. There are two types of consumers: one type has a strong preference for originals (call them high value consumers) and another type is indifferent whether the good is an original or a copy (call them low value consumers). Both types of consumers are distributed in a Hotelling-fashion between the two firms. Parameter restrictions are introduced which ensure that firms never compete for the low value consumers. The utility of a high value consumer located at ω from purchasing the good located at 0 is $\mu N - \omega - p + r$, while the utility of a low value consumer is $\mu N - \omega - p$ in this case. Copying gives for both types utility $\mu N - \omega$. In this specification, the benefit from purchasing the original, r, is independent of the network effect (contrary to Takeyama, 1994).

Under copy protection, there exist up to two types of symmetric equilibria: one equilibrium in which both firms price low so as to sell the good as well as to some low value consumers and another equilibrium in which both firms set prices

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[10] For each of the two groups of consumers, buyers of originals and "buyers" of copies, Gayer and Shy (2003) allow in principle for a network effect that depends on the number of buyers of the original and for another network effect that depends on the number of "buyers" of copies. They then assume that there are no intra-group network effects. However, the same result as theirs in Section 4 hold qualitatively if the intra-group and inter-group network effects have the same strength.

so as to sell only to the hi1gh value consumers (the original analysis by Shy and Thisse (1999) contains a mistake, which has been corrected by Peitz, 2003). Selling to high value consumers only is an equilibrium for sufficiently weak network externalities. Selling also to some low value consumers is an equilibrium for sufficiently strong network effects. When consumers can copy, firms can exploit network effects without selling to low value consumers. Suppose network effects are weak. Then the number of sold units is not affected by the copy protection policy. However, there is a price competition effect which leads to a downward pressure of prices. Consequently, profits fall. Suppose, on the contrary, that network effects are strong. To exploit some of these external effects firms have to price low if no copying is available. But if copies are freely available, they can concentrate on high value consumers and still reap the benefits from network effects. This leads to higher prices and profits. The reason is therefore similar to the one provided by Takeyama (1994), as explained above.

5. Consumer information and digital copies

Digital products and music in particular require some form of experimentation. Although testing new digital products has always been possible (listening to music in record stores, browsing books on the shelves, using a shareware version of a piece of software), legitimate authors have a hard time trying to monitor unauthorized copies in an interconnected world in which file-sharing technologies are available. Thus we can expect that digital copies will play a positive role for copyright owners, reducing costs to transmit information to consumers, and a negative role, reducing revenues due to copying.[11]

A number of recent articles analyze the informational role of unauthorized copies on firm profits and strategies as well as welfare.

Duchene and Waelbroeck (2002) analyze the effect of extended copyright protection on a firm's distribution and protection strategies, when digital copies available on P2P networks play an informational role. To this end they propose a simple model of P2P technologies in which an original provides additional value compared to the copy and where consumers are heterogeneous with respect to the opportunity cost of spending time online searching for files. They model the demand for a new product that is not distributed using the marketing/promotion technology by assuming that consumers can only purchase a good after they have downloaded a digital copy that provide information on the characteristic of the product.

They consider a single firm that decides how much costly technological protection to implement in different legal enforcement regimes. Technological protection increases the consumers' disutility of a copy but at the same reduces the fair use value of the original product (although they assume that the first effect dominates the second). A strengthening of legal protection reduces the surplus of copiers through the increase in the expected penalty if caught copying. In this

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[11] Interestingly, this may result in a reduced role for record companies, which are intermediaries between artist and consumers. Halonen and Regner (2003) analyze the contractual relationship between artist and label in a Grossman-Hart-Moore setting. They find that the present ownership structure in which the labels own most of the property rights is optimal when digital copies are not available. With new distribution and promotion technologies this may no longer be the case. See also Regner (2002).

framework, they show that increasing copyright protection has both a direct effect on copiers but also an indirect effect on buyers as technological protection and prices increase with legal protection, unambiguously reducing consumer surplus.

Peitz and Waelbroeck (2003a) analyze the informational role of copies in a multi-product environment. They consider digital copies and P2P as a means to obtain information that consumers otherwise lack. In their model a single firm sells N products that are horizontally differentiated. Consumers derive some utility from downloading a copy plus an additional utility associated with the purchase of the original of a product that they like, i.e., that is not too different from their ideal product. Consumers can obtain information on the horizontal characteristics of products by using P2P. Without the availability of digital copies, consumers have to choose at random between the N products. P2P allows users to sample. Thus consumers can obtain a very precise signal of the location of the products with respect to their own taste. Peitz and Waelbroeck show that for a sufficiently large number of products, the firm can benefit from the informational role of digital copies that leads to a higher willingness to pay for the original.

In an extended model they analyze P2P as an alternative channel of information transmission to marketing and promotion. They postulate that through marketing and promotion the firm can transmit information on the desirability of its products to consumers with some precision. This gives partial information on the horizontal characteristics of the products, i.e., marketing and promotion reduces the set of preferred varieties to $n < N$ and raises the expected value of the original. Transmitting more precise information is assumed to require higher fixed costs of marketing and promotion. Peitz and Waelbroeck then show that firms can reduce the cost associated with marketing and promotion in the presence of P2P, increasing profits. Indeed, P2P can be seen as a substitute to marketing and promotion. They conclude that even if P2P reduces revenues, profits may actually increase because of reduction in the distribution cost.

Stars versus niche performers. Zhang (2002) argues that sticking to the traditional distribution technology is wasteful from a social point of view when P2P technologies are available. His argument is motivated by the observation that the current distribution technology favors artists with a large audience (or stars) preventing marginal artists to be distributed in the market. P2P, by offering a cheaper way (digital copies) to give information to consumers, makes it possible for the marginal artist to enter the market. To make his point, Zhang proposes a model of the music industry with two products that are horizontal differentiated. The product is synonymous with the artist, where a star artist is pushed by a big label and the marginal artist has no backing. Zhang assumes that prices are exogenously fixed and identical for both products. Consumers have different values for each artist described by the unit interval on the Hotelling line. However, without piracy products are asymmetric because the value can be increased by persuasive advertising for one particular artist (the star) but not for the other (the marginal artist). Although the persuasive nature of advertising may be questionable, it is not essential for the argument (although welfare results depend on the particular specification of advertising).

The star artist chooses advertising expenditures to maximize his profits. Although the marginal artist is not naturally blockaded from distributing its product, the star artist (or, his label) will choose a positive amount of advertising

expenditures to distort demand in its favor. This distortion can be so large that the marginal artist can even be driven out of the market.

With piracy, the marginal artist can distribute his songs using a P2P technology. Zhang assumes that only a portion of consumers have access to P2P, that digital copies provide information on the true characteristics of the products and that a fraction of these consumers (the "honest" downloaders) purchases one of the two songs which provides the highest utility. Then clearly, when P2P exist, marginal artists can gain from the exposure effect, while the star unambiguously looses. This insight is likely to go through in a less simplistic model in which both artists have a set of strategies available. The basic point would be that in an asymmetric world (with stars and niche performers) the current distribution technology favors the promotion of stars. With digital copies niche performers can more easily access consumers. In effect, the distribution of album sales would be less skewed.

Copying and adverse selection. Takeyama (2002) analyzes how copies that provide information on the quality of a product can solve an adverse selection in models of asymmetric information. She considers a monopolist selling a durable good that can have two exogenous qualities (high and low) known to the firm, but unknown to the consumers (who, for simplicity, do not value the low quality). There are two periods and all consumers with unit demand live in both periods. Without copies, Takeyama assumes that a high-quality firm cannot make profits because of the underlying adverse selection problem.

Consider now the situation when copies are available. If a consumer copies the product in the first period, she learns its quality and can decide whether to purchase in the second period. Takeyama assumes that copies give less value than the original. Hence, it may be worthwhile to buy the good after copying. Furthermore, there are two groups of consumers, who receive different values from the copies (in our previous notation, $\alpha_L \theta q$ and $\alpha_H \theta q$, respectively). A copy can be obtained at price c (that is, there is a disutility from copying). Under some parameter restrictions a fraction of consumers (those consumers with parameter α_L) never copy – call them the captive consumers – regardless of the price and the true high quality (in other words, the reproduction cost is larger than the benefit of the copy for them). The other consumers have the possibility to copy in the first period and then to buy the original if the product turns out to be of high quality. Takeyama shows that there exists a pooling equilibrium in which the monopolist intertemporally price-discriminates, selling to the captive consumers in the first period and charging the price equal to the difference in valuation between the original and the copy to the other consumers in the second period (at a price equal to $(1-\alpha_H)\,\theta q$). In this equilibrium, a high-quality firm can make profits due to the informational gain brought by copies. Interestingly, consumers with a low value for copies would generate higher price-cost margins in a static discrete choice setting. However, copying provides information and those with a high value for copies are more likely to engage in copying. This solves the adverse selection problem for high quality.

Furthermore, in a separating equilibrium with copying the quality may be revealed to consumers prior to purchase, whereas low quality does not enter the market. Takeyama then makes the availability or non-availability of copies part of

the firm's strategy. She shows that the presence of copies (in other words, the lack of enforcement of copyright) is a signal for high quality.

We note that if the firm could choose quality then it may have an incentive to do so when copies are available but not when copies are not available (the model then would become a model of moral hazard). We conjecture that the following situation can then arise: if the copyright enforcement is part of the strategy, a firm has an incentive to provide high quality. If piracy was made impossible no product would be available. Consequently, the possibility of piracy can provide incentives for the provision of high quality in a market which otherwise would not be served. While the aspect of consumer learning is certainly of importance in several markets, Takeyama's intertemporal pricing context is perhaps of limited applicability.

6. The Applicability of the Models to the Analysis of Copying of Software, Online Games and Digitally Compressed Music

While digital products share several features with each other (almost zero marginal costs of production, almost perfect copy), illegal digital copies of certain goods are in reality not perfect substitutes to originals. We discuss economic aspects of software, online games, and music P2P in the light of the insights given in the literature that we have reviewed.

The following table provides a crude summary of the relevance of various features of the market for the following product categories: software, online games, and digitally compressed music. With "0" we mean that this is unlikely to be an important feature for that product category, with "+" we mean that this is likely to be an important feature for that product category.

	Software	Online Games	Digitally Compressed Music
Indirect Appropriability	+	0	0
Network effects	+	+	0
Informational role of free copies	0	0	+

Table 1: features of digital products

6.1 Software
In many cases, the developer of the software offers different versions of their product, probably more to price discriminate than to deter piracy. Because of the complexity of the products, the "true" cost of a piece of software is not only its purchase price, but rather includes the cost to learn how to use the software to its

full potential and to make it work with other software (this is sometimes referred to as TCO or Total Cost of Ownership). For this reason, some users place a great value on manuals, which gives a higher value to the original than to the downgraded version or copy.

It is easy to monitor software copies in large companies and administration or even small businesses because a single threat of visiting the company for a pirated version of a software is in general enough to trigger purchases of the original. Also note that the cost of copying a piece of software can be large. First, because of the complexity of the product the likelihood that one installation file is corrupted or missing is high. Secondly, installing pirated software requires some technical knowledge and can lead to an unstable computing environment; this technical knowledge is costly. If the pirated software is not installed properly, the copy is of inferior quality. Because of these legal and technological barriers, there is some indirect appropriation in the form of site license agreements that typically depend on the number of computers using the software.

Network effects, although very strong in the past, have been reduced following the development of standards for file formats. Therefore, it seems that the argument of using copies to promote sales of originals is weakening. Important exceptions are online games and applications (see below), online collaboration and instant messaging (including video conferencing), where full compatibility is critical.

Software producers have for a long time used the practice of offering their product for free, either the full featured version or a downgraded version for a limited time only (these copies are often designated as "shareware"). Indeed, a new piece of software is typically an experience good that needs to be used before evaluating all its benefits. Hence, there is potentially a role for digital copies to provide information on the characteristics of the original product.

6.2 Online games

This category of digital products is interesting to analyze for two reasons. First, the protection policy has changed over the last decades. While games developed in the 1980s were strongly password as well as technically protected, the quality difference between the original and the copy was low. With the explosive growth of computing power, game developers have changed their protection strategies by dramatically increasing the quality of the original (including sounds, speeches, videos, cinematic effects), making the purchase of the original game a great value compared to the copy. At the same time, the number of games using password protection and technical protection has decreased.

Secondly, contrary to what might have been expected, the development of the internet has not had negative effects on sales of computer games. Quite the contrary. Because games that have an online component require to connect to a proprietary site (using a unique identification number), it is to easy monitor connection and the number of uses of the game, without implementing fancy Digital Rights Management (DRM) technologies that can monitor and limit the number of uses of a digital product. Thus, copies have no value since they do not provide an additional identification number.

In principle, online game developers could fully price discriminate consumers according to their use of the software. In practice, firms do not price discriminate. An economic reason may be that heavy gamers are often teenagers or young adults with low income (wealthy people in general have the largest opportunity cost of spending hours playing online games). Also price-discrimination may be difficult to implement when a firm faces fierce competition.

By the nature of the products, network effects are very strong as users want to play with their friends and form online communities. Because digital copies have no value, the informational role of these copies is extremely limited.

Software Application Providers (SAP) is a related category of digital products for which the same economic analysis applies. Indeed, providers of online applications can also monitor the use of any subscriber and network effects are strong.

6.3 Music/P2P

Music is a typical experience good. The internet has made it easier for consumers to try new music by downloading Mp3 files but searching for files even in a world of broadband connection is time consuming. There are several reasons. First, file names do not always correspond to the requested file; they can be corrupted and the downloading speed depends on the priority rating of the user in the P2P network. Secondly, song and title information are often poorly documented and getting this information is also costly. Thus, a digital copy (from a P2P system) provides less value than an original but at a lower cost. This cost depends on the user's opportunity cost of spending time online.

With respect to the cost of burning a CD, of course, the total cost also includes the purchase of blank CDs and CD recorder. Hence there exists a fixed cost of copying and a constant marginal cost of creating CDs (which may include the opportunity cost from downloading and burning). However, since CD writers are versatile their costs typically cannot be fully attributed to making music CDs.

From a purely technical point of view, the expected quality of the copy is lower because of the compression algorithm and the probability to download a wrong or incomplete file. In addition, some consumers greatly value pictures, lyrics and music information (as illustrated by the sales of merchandizing) making a digital copy a lower quality product because it lacks valuable characteristics.

In principle, DRM is a tool to fully appropriate the values of the copies as well as to price discriminate. However, such technological protection seems hard to implement, since it is always possible to crack software protection and diffusion of these anti-protection devices would be fast in P2P networks.

Even without DRM, it would be in theory possible to indirectly appropriate revenues from the "uses" if the file-sharing rating of a user depends positively on the number of uploads and negatively on the number of downloads and if the rating itself makes searching and downloading faster (see Liebowitz, 2003). Indeed, users would be ready to purchase the original at a higher price as they expect many other users to download the file, thus improving their rating. Of course this mechanism would work best for music with a strong and temporary

demand, thus favoring star artists. While indirect appropriation may work for members of the P2P community, the fact that an important number of potential buyers does not belong to it, makes it unlikely that labels can profitably increase the price of a CD to indirectly appropriate revenues.

There is a case for weak network effects in music consumption if users place a value on the number of people listening to the same music. These social network effects can result from the fact that consumers want to belong to a community or be able to talk about music in social gatherings. In principle, network effects could depend on both the number of originals and copies.

There is a different reason for the existence of network effects among copiers using file-sharing technologies. Clearly, the speed of downloading music files will be faster with the size of the network. These network effects are endogenous in the sense that users of file-sharing technologies can decide whether to share their files or not. This decision typically depends on the expected gain in the user's rating (making it easier for him to download new songs in the future) and the cost of sharing related to the probability of being caught by legal authorities or receiving a virus and the loss of computer resources. However, if there are only a few number of users sharing many files, the extent of network effects is limited (for a discussion see Peitz and Waelbroeck, 2003b).

When facing new music, consumers like to spend time getting recommendation from music magazines, listening to music on the radio or in record store before making their purchase decision. The traditional way for record companies to provide information to consumers on the existence and the genre of new CDs and artists is to spend large costs on advertising and promotion. However, after the Napster experience, it has become clear that there is a cheaper way for consumers to obtain this information, by searching, downloading and testing digital music files made available through P2P or other file-swapping technologies. This information transmission technology is rather different from traditional ads/promotions, as consumers not the firms are spending time and resources. In a sense, it is information-pull against information-push technologies. To sum up, digital copies of music files can be expected to have a strong informational role.

6.4 Other Digital Products
Clearly, there exist other digital products, which have not been discussed: for instance, *video games* (for the consoles of Sony, Sega, or Nintendo). In this industry developers sell the games in a proprietary hardware format. The technology of copying video games is specific. There is a large fixed cost of purchasing a copying device (which does not have alternative uses) and then a very low marginal cost for each additional copy. Thus only users who play a lot can find it profitable to copy. However, here the original and the copy have almost the same quality. Since the need to have an extra copy is low and the cost is high, there is a low potential for indirect appropriation.

Although most of these games are played alone, there are some games where players can compete against each other or that require some interaction with other people. For these reasons, one can expect weak network effects. Note also that sampling does not play a role because of the lack of free copies.

Another related product is *movies on DVDs*. So far, movies have not faced serious competition from free illegal copies. There are several reasons. First, movies are much more storage hungry, so that downloading is much more cumbersome and time-consuming. Secondly, similar to video games, copying DVDs is hardware protected. (This partly explains the music industry's enthusiasm for music DVDs). Thirdly, the copies that are available for free on the internet are of much lower quality than the originals so that they are not a threat to the original (no choice of format, language and subtitles, no extra material). Clearly, this is a snapshot. It is to be seen whether at some point in the future digital copies distributed through file-sharing systems become a substitute to movies sold on DVDs. As long as this is not the case, digital illegal copies probably have a negligible effect on DVD sales.

Summarizing, models with network effects are well-suited for the analysis of software copying while other models incorporating the feature that copies provide information about the originals may be useful for the analysis of digital music copying.

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