The Provision of (Two-Way) Converters in the Transition Process to a New Incompatible Technology

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Abstract

This paper analyzes the dynamic provision of converters in the transition process between two incompatible technologies. I derive the equilibrium behavior in the provision of converters and compare it to the socially optimal outcome. I find that there can be two types of market inefficiency in the provision of converters. First, converters can be supplied by the "wrong" group. Second, the timing of provision may be too late since the providers of converters ignore the positive externality that their patronage would confer on the users of the rival technology.

I. Introduction

This paper analyzes the provision of (two-way) converters in the transition process between two incompatible technologies with network externalities. Consider the following situation. Potential users arrive gradually over time and continue to adopt only one technology available before some time T, at which a new incompatible technology appears. The new technology is assumed to be so superior to the old one that new consumers adopt the new technology even though they have to give up the benefit of compatibility with the installed base of the old one.

In such a situation, I allow for the availability of symmetric *two-way* converters that confer the same degree of partial compatibility benefit not only on its owners but also on users of the rival technology. As emphasized in David and Bunn (1988) and modeled by Farrell and Saloner (1992) in a static context, compatibility and standardization is a matter of degree and the extent of incompatibility can be reduced by the availability of converters. Converters, however, are often costly. This, in conjunction with the public good characteristic of converters, implies that each user group of incompatible technologies will prefer to free-ride on the converters provided by the other group.[1] I derive the equilibrium behavior in the provision of converters and compare it to the socially optimal outcome. I find that there can be two types of market inefficiency in the provision of converters. First, converters can be supplied by the "wrong" group. Second, the timing of provision may be too late since the providers of converters ignore the positive externality that their patronage would confer on the users of the rival technology.

One salient feature of the dynamic public good provision considered in this paper is that the strategic strength of each group to outwait the other to provide public goods can change over time due to a continuous inflow of new consumers. The value of and the

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[1] If converters were one-way, enabling only those who have them to derive some network benefits from users of the other technology, but not the other way around, the provision of converters would not involve any externality. Therefore, there would be no inefficiency associated with the provision of converters. See Farrell and Saloner (1992) for the discussion of various types of converters.

incentive for purchasing a converter increases with the network size of the (incompatible) rival technology. This implies that the relative ability of each group to impose the burden of public good provision on the other group depends on the relative size of their network. In my model, at the advent of the new technology, the owners of the old technology enjoy a strategic advantage over new consumers due to its installed base; it will take time for the network of the new technology to grow. Eventually, however, the new network will outgrow the old one. This paper explores the implications of this change over time in the relative network size for the provision of converters.

This paper is also related to a small but growing number of papers dealing with the implications of gateway technologies in the compatibility literature. In a detailed case study of electric supply systems, David and Bunn (1988) document how the discovery of a converter (or gateway technology in their terminology) can tip the balance in the battle for *de facto* standards. In a recent paper, Farrell and Saloner (1992) explore the implications of converters in the adoption of technology when there is a conflict between variety and compatibility benefits. Contrary to the common beliefs that converters make possible the joint benefit of variety and network externalities, they show that the existence of converters can actually lead to less compatibility than would prevail in the absence of converters. Their model, however, is essentially static and is limited in its ability to determine who actually supplies converters when two incompatible technologies are coexistent. In their model, any equilibrium in which converters are purchased is asymmetric despite the assumption of *ex ante* symmetric technologies. Therefore, they have to rely on an arbitrary assumption of coordination to break symmetry. My model provides a more systematic answer to the question since it, by virtue of being dynamic, analyzes competition between naturally asymmetric technologies: one with a pre-installed base and the other without one.

The paper is organized in the following way. Section II sets up the basic model. In Section III, I analyze the private incentives to provide converters in the transition process from an old technology to a new, but incompatible, technology. Section IV compares the decentralized market outcome with the socially optimal one and identifies possible market inefficiencies. Concluding remarks follow with a discussion of possible extensions.

II. The Model

The basic set-up is a variant of Farrell and Saloner (1986) with the exception of the availability of converters. I consider a continuous time framework in which consumers arrive sequentially over time. They are assumed to be infinitesimal. The timing is normalized by assuming that only technology U is available before time zero, at which point a new technology V becomes available unexpectedly. The assumption of unexpected availability of the new technology spares us the need to analyze the waiting option for the consumers before time zero.[2] I assume that these two technologies are supplied competitively or unsponsored in the terminology of Arthur (1989).[3] The marginal costs of these two technologies are assumed to be constant over time, which implies that prices are also constant over time. A consumer who has technology U enjoys a flow benefit of $\alpha+\beta N_t$ at date t if the network size she belongs to at time t is N_t, $\alpha, \beta > 0$. We can interpret α as a network independent benefit (net of amortized cost of the old technology) and β as a parameter representing the strength of the network benefit. A consumer who has technology V, which is assumed to be incompatible with U, enjoys a flow benefit of $\alpha'+\beta N_t$. The interpretation of α' is the same as α applied to the new technology. Since technologies U and V share the same parameter β, both technologies are assumed to confer the same degree of network benefit if they have the same network size. Future flow

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[2] In contrast, Katz and Shapiro (1992) endogenize the timing of new technology introduction in a model with technical progress. They also allow consumers to wait until the introduction of a new technology. However, in their perfect foresight equilibria consumers never exercise their option to wait since there is no uncertainty regarding the future value of the technology. See Choi (1994 a) for a model in which the waiting option is explicitly analyzed.

[3] Katz and Shapiro (1986) examine the dynamics of competition between incompatible technologies in a market where the sponsors of those technologies engage in strategic pricing.

benefits are discounted using the constant interest rate of r. I further assume that the price of each technology is sufficiently high to not justify scrapping the old unit and to buy a new one.[4] This assumption is meant to capture the fact that "new users have an option that was unavailable to previous users, and moreover, those (the installed base) who had previously adopted the old technology may be at least somewhat *committed* (Farrell and Saloner, 1986, italics original)." I denote the number of consumers already having technology U at time zero by I (for installed base). The rate of continuous arrival is normalized at n; the number of consumers arriving between time t and t + dt is simply ndt.

Typically, converters are not perfect and entail the degrading of performance. Therefore, I follow Farrell and Saloner (1992) in assuming that converters confer only a fraction of the full compatibility benefit.[5] If the size of the incompatible network is N, the purchase of a converter gives rise to the network benefit of $\beta(1-q)N$ in addition to the benefit from one's own network . The parameter q represents the degree of degradation in performance, meaning that a lower q corresponds to a better converter. It is assumed that converters are supplied competitively at the price of c, which is constant over time.

III. The Purchase Decision for Converters

In order to abstract from the analysis of how the availability of converters affect the patterns of technology adoption, I assume that the intrinsic advantage of the new technology ($\Delta = \alpha' - \alpha$) is so large that it is a dominant strategy for new consumers to adopt

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[4] For an analysis of technology choice in the presence of network externalities when consumers are allowed to make repeat purchases, see Choi (1994 b) and Waldman (1993).

[5] For instance, recently an alliance of Motorola, IBM and Apple Computer introduced the Power PC, a new processor based on RISC (Reduced Instruction-Set Computer) technology. Even though the Power PC is estimated to be faster than Intel's (currently) most advanced Pentium chip, it cannot readily run most of the applications software that run on Intel-based computers. A conversion technology makes it possible for a Power PC to run existing Intel-based softwares. However, converters restrain processors and make a Power PC run no faster than a basic Intel 486 [see *The Economist,* February 12th, 1994, pp.59-60]. See Farrell and Saloner (1992) for more examples.

the new technology irrespective of which type of users provide converters.[6] Since converters are assumed to be "two-way", only users in one network need to patronize converters in order for both user groups to take advantage of the network benefits of the others. Therefore, converters will have a public good characteristic; each user group prefers the other to supply converters.

I first analyze the optimal timing to purchase converters for consumers in the old network, assuming the most pessimistic expectation for them, namely that newly-arriving consumers never supply converters. It should be noted that even if all newly-arriving consumers adopt an incompatible new technology and eventually purchasing converters is a worthwhile investment for the installed base users, they will not buy immediately after newly-arriving consumers start adopting the new technology. The reason is that it takes time to build a network on the new technology; they will wait until the new network reaches a certain size. By postponing the purchase they will forgo some initial network externalities. However, interest rates on the costs of converters can be saved. The optimal time for the old consumers to purchase converters (assuming that newly-arriving users never buy converters) solves the following maximization problem.

$$\max_{T} \int_{T}^{\infty} [\beta(1-q)nt]\, e^{-rt}dt \ - ce^{-rT} \qquad (1)$$

The first order condition for the optimal adoption time is given by:

$$-\ \beta(1-q)nT\, e^{-rT} - r\, c\, e^{-rT} = 0 \qquad (2)$$

The first term in Equation (2) is the loss of network externality by postponing the purchase of the converter and the second term is the saving of interest costs from the delay of purchase. At the optimal time of purchase, the marginal benefit of delay will be equated to the marginal cost. Rewriting the first order condition gives us the following optimality

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[6] In Choi (1993), I analyze the effect of converters on the equilibrium technology adoption patterns. If there are changes in the adoption behavior due to the existence of converters, I also compare the welfare consequences of the changes in the adoption regimes.

condition.

$$T^* = \frac{r\,c}{\beta(1-q)n} = \frac{\rho}{n}, \text{ where } \rho = \frac{r\,c}{\beta(1-q)}. \tag{3}$$

Since the optimal time of purchase in (3) is derived under the most conducive assumption for the old group to supply converters, we can say that T* is the earliest time possible for the old group to buy converters. In other words, it is a dominant strategy for the old group to wait until T*, which implies that the old group is committed to not buying converters until T*. Equation (3) says the optimal time is proportional to the flow cost-benefit ratio of converters (ρ) and inversely related to the growth rate of a new network (n).

Now let us analyze the newly-arriving consumers' incentive to provide converters. The incentive will depend on the size of the installed base of the old technology. Suppose that $\frac{\beta(1-q)I}{r} \leq c$. Then, the installed base of the old technology is so small that the compatibility benefit from it does not justify the costs of converters for the newly-arriving consumers. Therefore, it is a (weakly) dominant strategy for them not to buy converters. Given this, it is an optimal strategy for the installed base users to buy converters at time T*.

If $\frac{\beta(1-q)I}{r} > c$, then there exists a unique I* which is defined by:

$$\int_0^{T^*} [\beta(1-q)I^*]\, e^{-rt} dt = c \tag{4}$$

In other words, I* is the size of the installed base which makes a newly-arriving consumer indifferent to buying the converter herself or waiting until the installed base users buy at time T*.

If I>I*, the unique equilibrium is for each newly-arriving consumer to buy the converter immediately upon her arrival in the market since she would rather provide a converter herself than wait until T* even though she is sure that users on the installed base will supply converters. The reason has something to do with the commitment power of the old consumers engendered by their installed base. Even though the new network eventually outgrows the size of the old network and becomes the dominant technology, all the costs of converters will continue to be borne by newly-arriving consumers. The reason is that, in making the purchase decision for converters, the relevant size of the rival network is *not* the total number of consumers subscribing to the rival technology but only the number of those who do not own converters. Consequently, as newly arriving consumers purchase converters the new network will never gain a strategic position vis-à-vis the old network. The dynamic features of my model, therefore, yield a sharp contrast to the prediction of Farrell and Saloner's (1992) static model in which converters are always supplied by the owners of the minority technology.

If I< I*, then there exist multiple equilibria since the game exhibits the payoff structure of the war of attrition. Suffice it to mention that there are two pure strategy equilibria: one is for newly-arriving consumers to buy immediately as they arrive and the other is for the old consumers to buy at T*. These two are the most efficient equilibria. Any other mixed equilibria entail inefficiency due to the delay in the provision of converters. Since I am interested in demonstrating inefficiency in the market outcome, there is no loss of generality; the focus on the most efficient equilibria in the decentralized economy only makes my task harder. The discussion above can be summarized in the following Proposition.

Proposition 1. In a decentralized economy, who purchases converters is determined by the size of the installed base at time zero (the timing of a new technology introduction).

(i)If $I \leq \rho \ (= \frac{r\ c}{\beta(1-q)})$, then users on the new network never buy converters and users on the installed base buy converters at time T*.

(ii) If $I > I^*$, newly-arriving consumers supply converters as they adopt the new technology. I* can be derived substituting (1) into (4), which is given by:

$$I^* = \frac{rc}{\beta(1-q)\left[1 - e^{-\frac{cr^2}{\beta(1-q)n}}\right]} = \frac{\rho}{1 - e^{-\frac{r}{n}\rho}} \quad (>\rho) \qquad (5)$$

(iii) If $\rho < I \leq I^*$, there are two pure strategy equilibria. One in which newly-arriving consumers supply converters as they arrive and the other in which users on the old network supply converters at time T^*.

IV. The Social Optimum

Now let us analyze the social optimum. Social welfare is defined as the discounted sum of consumers' welfare net of the production cost of converters. It should be pointed out that an outcome in which subsets of users in both networks purchase converters cannot be socially optimal; we can find a better outcome in which the purchases are concentrated in only one group. Therefore, in any socially optimal outcome, users in only one network will buy converters. Suppose that it is the new technology network that supplies converters. Since the size of the installed base is constant, it is best to buy as consumers arrive on the scene. Therefore, there is no discrepancy in the timing of adoption (I ignore the case where the war of attrition occurs in the market outcome). The discounted present cost of converters is given by:

$$C_N = \int_0^\infty nc\, e^{-rt}\, dt = \frac{nc}{r} \qquad (6)$$

Now suppose that it is the network of the installed base who provide converters. Then, the socially optimal purchase time is found by solving the following.

$$\max_T \int_T^\infty I\,[\beta(1-q)nt]\, e^{-rt}dt + \int_T^\infty nt\,[\beta(1-q)I]\, e^{-rt}dt - I\,ce^{-rT} \qquad (7)$$

The integrands in the first and second integrals are the discounted network benefits from converters (purchased at time T) for the installed base and new consumers. With the linear arrival rate and linear network externalities, they happen to be the same even though they will be different with more general functional forms.[7] The socially optimal purchase time

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[7] Suppose that the network benefit function is given more generally by $B(x)$ when the size of the compatible network is given by x. Converters are assumed to increase the size of

is given by T^0:

$$T^0 = \frac{r\,c}{2\beta(1-q)n} = \frac{\rho}{2n} = \frac{T^*}{2} \tag{8}$$

Therefore, we can conclude that when old consumers purchase converters, they tend to adopt too late compared to the socially optimal timing. The reason is the familiar positive externality argument. When they provide converters, they also provide positive benefits to newly-arriving consumers, which is ignored in the purchase decision of individual decision-makers. For the optimal outcome, we have to compare the costs of providing converters by each group taking into account the timing of purchase. Note that there are two kinds of costs associated with the purchase by the old group. The first one is the direct cost of providing converters, which is given by $I\,c\,e^{-rT^0}$. There is an additional cost of incompatibility since users on the installed base will not buy converters immediately upon availability of the new technology, while with new consumers buying converters there is always partial compatibility through converters between the two networks. Combining these two costs, we have the following costs when the old group supplies converters:

$$C_O = I\,c\,e^{-rT^0} + 2\int_0^{T^0} I\,[\beta(1-q)nt]\,e^{-rt}dt \tag{9}$$

Substitution of (8) into (9) yields the following expression for Co:

$$C_O = I\left[c e^{-r\frac{\rho}{2n}} + \frac{2cn}{r\rho}\left(1 - e^{-r\frac{\rho}{2n}} - r\frac{\rho}{2n}e^{-r\frac{\rho}{2n}}\right)\right] \tag{10}$$

Therefore, the condition for $C_N > C_O$ can be derived as follows:

$$I > I^0, \text{ where } I^0 = \frac{\frac{\rho}{2}}{1 - e^{-r\frac{\rho}{2n}}}$$

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the compatible network by (1-q) times the size of the otherwise incompatible rival network. Then, the network benefits from converters will be given by

$$\int_T^{\infty} I\,[B(I + (1-q)nt) - B(I)]\,e^{-rt}\,dt \quad \text{and} \quad \int_T^{\infty} nt\,[B(nt + (1-q)I) - B(nt)]\,e^{-rt}\,dt$$

for the installed base and new consumers, respectively. However, the qualitative results in this section do not depend on the specific functional forms assumed.

Proposition 2 summarizes the discussion above.

Proposition 2. The socially optimal decision of who purchases converters and the timing of their purchase are also determined by the size of the installed base.

(i)If $I > I^0$, the newly-arriving consumers should buy converters as they arrive.

(ii) If $I < I^0$, it is the old group who should purchase. The socially optimal timing of the purchase is given by T^0.

An immediate consequence of Propositions 1 and 2 is the following Corollary regarding the discrepancy of the socially optimal and market outcomes, which can be summarized in Figure 1.

Corollary. We can identify two kinds of market bias compared to the socially optimal outcome. First, when users on the old network buy converters, their purchase time is too late compared to the socially optimal timing. Second, the wrong group can end up buying converters. The identity of purchase group is determined by I^* in the market outcome while it is I^0 which determines the socially optimal outcome.

It can be easily verified that for all parameter values of (r, β, c, n, q), we have $I^* \geq I^0$. Moreover, $\rho \geq I^0$ if and only if $\rho \geq n\,(2\ln 2)/r$. With the special case of a linear network benefit function and constant rate of arrival, we can have the following types of inefficiency.[8]

Case I: $I^0 \leq \rho < I^*$ or $\rho \geq n\,(2\ln 2)/r$ [9]

(i) If $\rho < I < I^*$, there are multiple equilibria in which either newly-arriving

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[8] If $I > I^0$, then the market outcome and the efficient outcome coincide.

[9] From equation (5) we already know that I^* is always larger than ρ.

consumers supply converters as they arrive or the installed-base users purchase converters at time T^*. For efficiency, newly-arriving consumers should supply converters.

(ii) If $I^0 < I < \rho$, newly-arriving consumers should supply converters as they arrive. However, in equilibrium, the installed-base users supply converters at time T^*.

(iii) If $I < I^0$, in both the market equilibrium and the social optimum, the installed-base users supply converters. However, the timing of provision is later than the socially optimal one ($T^* > T^0$).

<u>Case II</u>: $\rho < I^0 < I^*$ or $\rho < n\,(2\ln 2)/r$

(i) If $I^0 < I < I^*$, we have the same situation as (i) in case I.

(ii) If $\rho < I < I^0$, there are multiple equilibria in which either newly-arriving consumers supply converters as they arrive or the installed-base users purchase converters at time T^*. For efficiency, the installed-base users should supply converters at T^0 ($<T^*$).

(iii) If $I < \rho$, we have the same situation as (iii) in case I.[10]

[Insert Figure 1 about here]

IV. Concluding Remarks

I analyzed the dynamic provision of converters in the technology transition process between two incompatible technologies. It was found that the owners of the old technology can perpetuate its initial advantage stemming from the preinstalled base and force newly arriving consumers to buy converters even after their network size has been outgrown. I also compared the market outcome in the provision of converters with the socially optimal one.

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[10] With a more general network benefit function and non-constant arrival rates, we can have a situation in which $I^* < I^0$. In this case, there can be an additional type of inefficiency; if $I^0 < I < I^*$, in the equilibrium the new consumers supply converters but for efficiency the old group should supply converters at T^0.

My analysis has been predicated on the assumption that the new technology is so superior that the newly arriving consumers decide to adopt a new incompatible technology independent of the provision of converters. A natural extension of this analysis would be to dispense with this assumption and incorporate the analysis of the provision of converters into a larger framework of technology adoption. In Choi (1993), I conduct such an analysis. More specifically, I analyze how the availability of converters can affect the process of transition in standards between incompatible technologies. Contrary to a common presumption that converters facilitate the transition from an old technology to an otherwise incompatible new technology, I find circumstances in which the possibility of transition is blocked by the existence of converters.

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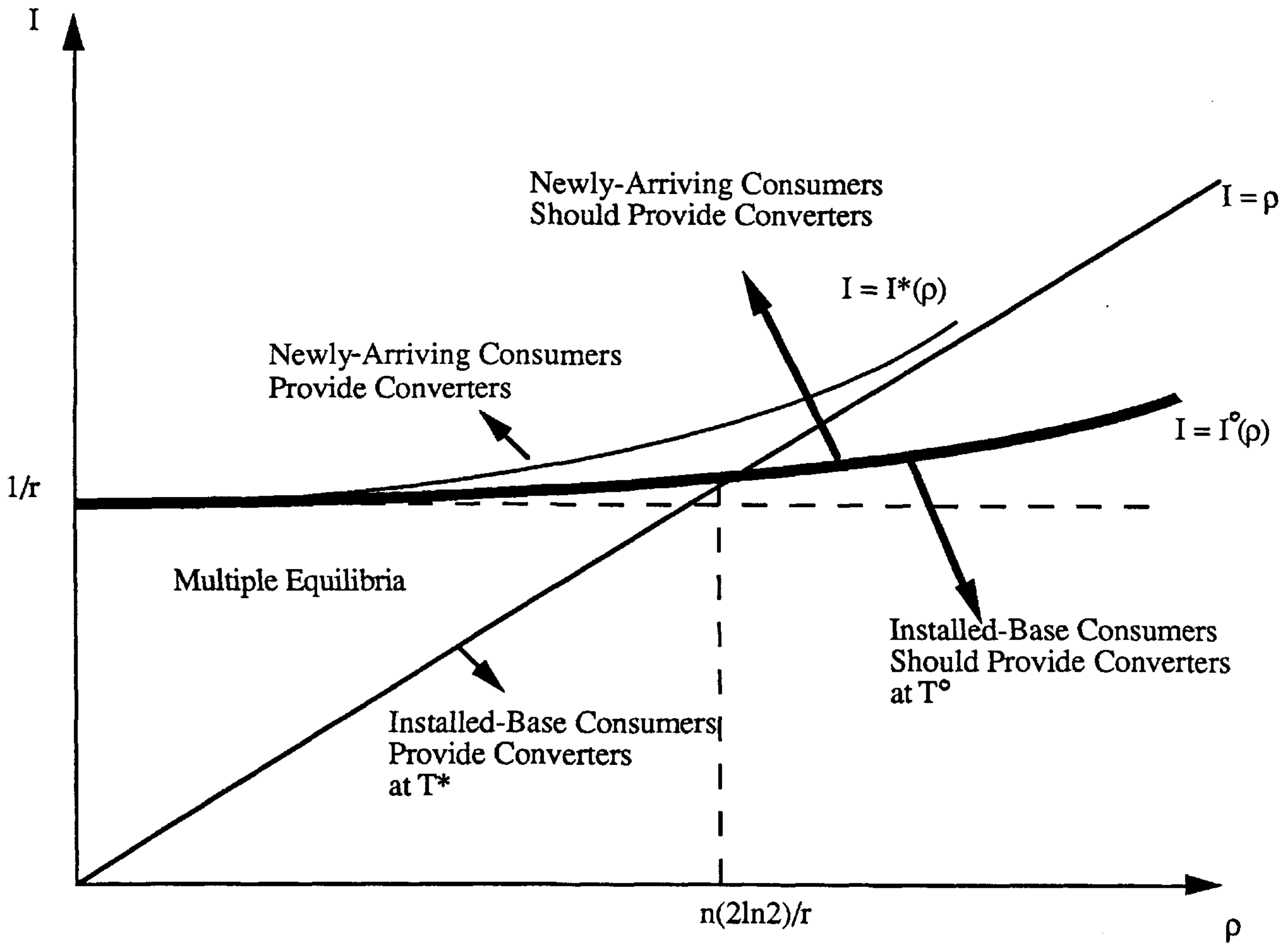

Figure 1: Equilibrium vs. Optimum in the Provision of Converters. The socially optimal outcomes are divided by a thick line while market equilibrium outcomes are divided by thin lines.

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