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A note on Critical Masses, Network Externalities and Converters.†

Abstract

Witt [9] demonstrates that superior technological standards have smaller critical mass, so that they can easily displace inferior alternatives. This note builds on his model to show that the critical mass of a given technology depends upon its efficiency *and* its compatibility with the existing standard, and hence that more efficient technologies need not have smaller critical masses. Some consequences for the economics of converters and "gateway technologies" are also discussed.

Keywords: Critical Masses, Lock-in; Network externalities; Standardization.

JEL classification: C73; L10; O31; O33

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1 Introduction

The idea that markets subject to network externalities get stuck into the first technological standard that gains a head start is usually defended by means of evolutionary models in which agents are assumed to be myopic and limitedly rational (Arthur [1] and David [2]). Alternative models based on more stringent assumptions of rationality tend to show that this is not necessarily the case. Rational and forward-looking agents can escape the lock-in trap created by increasing returns and network externalities.[1]

However, even authors who embrace an evolutionary approach do not necessarily believe that lock-in is the inevitable fate of this kind of markets. For instance, Witt [9] discusses an evolutionary model in which superior technological standards can displace inferior ones. He argues that a transition towards a new (and superior) standard can be started by a "diffusion agent" (Rogers [8]), an entrepreneur who bears the cost of persuading an initial fraction of consumers to make the first move. In the first stages of the transition process, the adoption of the new (and superior) standard is detrimental for the individual adopter. However, once a critical mass of adopters has been reached, people will spontaneously switch from the old to the new standard. Witt notices that the diffusion agent's task is easier when the critical mass is low, because in this case for a transition to take place a smaller fraction of initial adopters needs to be persuaded. In the model he discusses, more efficient technologies have

[1] "Although it seems plausible that the inertia associated with network effects has somehow deprived us of valuable new technologies, it is abundantly clear that many new, incompatible technologies are in fact successfully introduced. In fact, there is no general theoretical result implying excess inertia in market equilibria." (Katz and Shapiro [7]). See also the results discussed in Farrell and Saloner [4] ("symmetric excess inertia (a Pareto-superior new technology not being adopted) could not occur with complete information, although it could occur with incomplete information", p. 940.)

smaller critical masses, and he concludes that while market competition will never displace a technological standard with an equivalent alternative, it is usually open to novelties that represent an improvement over the *status quo*. As in other fields of economics, in markets characterized by network externalities "technological change is not merely change - it has to be progress in the sense of delivering economic advantage to the individual adopter." (767-8)

In this note I elaborate on Witt's approach to reach two results that are only partially compatible with his own conclusions. *First*, I show that the critical mass of a technology depends not only upon its efficiency, but also upon its compatibility with the existing standard. Hence, the selection process will favor not so much *efficient* technologies, but rather technologies that are *compatible* with the already established alternative. *Second,* I show that the diffusion agent will try to manipulate the new technology to reduce its critical mass. The paper characterize some technical conditions under which this battle for a smaller critical mass is likely to bring about more compatibility among competing standards.

2 A simple model of technology adoption

Two partially incompatible technologies V_1 and V_2 are available to consumers in a given market. An interaction between two agents is represented by the stage game in Table 1. The entries of the payoff matrixes are such that: $\pi(V_1, V_1) > \pi(V_2, V_1)$ and $\pi(V_2, V_2) > \pi(V_1, V_2)$. These conditions imply that the game has two pure strategy Nash equilibria: (V_1, V_1) and (V_2, V_2). I will assume throughout that technology V_2 is more efficient than technology V_1, so that $\pi(V_2, V_2) > \pi(V_1, V_1)$.

	V_1	V_2
V_1	$\pi(V_1, V_1), \pi(V_1, V_1)$	$\pi(V_1, V_2), \pi(V_2, V_1)$
V_2	$\pi(V_2, V_1), \pi(V_1, V_2)$	$\pi(V_2, V_2), \pi(V_2, V_2)$

Table 1: Technological adoption as a coordination game

The market is made of a large number of agents. At each point in time t a fraction $F(t)$ of the population adopts technology V_1. Each member of the population is repeatedly paired randomly with other members to play the stage game in Table 1. Let $\pi(V_i, F(t))$ be the expected payoff yield by technology V_i when the state of the population is $F(t)$ $(i = 1, 2)$. Under uniform random matching we have:

$$\pi(V_i, F(t)) = F(t)\pi(V_i, V_1) + (1 - F(t))\pi(V_i, V_2)$$

I assume that agents revise their strategies in such of way that $F(t)$ changes over time according to the differential equation

$$\frac{dF(t)}{dt} = g(\pi(V_1, F(t)) - \pi(V_2, F(t))) \tag{1}$$

where $g(.)$ is a sign preserving function and $g(0) = 0$. (See for example Witt [9], Proposition 2 and Proposition 2'.) The long-run behavior of the selection process is fully described by the following magnitude:

$$\phi^* = \frac{D_2}{D_1 + D_2}. \tag{2}$$

where $D_1 = \pi(V_1, V_1) - \pi(V_2, V_1)$ and $D_2 = \pi(V_2, V_2) - \pi(V_1, V_2)$. ϕ^* is the *critical mass* of technology V_1, while $(1 - \phi^*)$ is the *critical mass* of technology V_2. If an agent expects a fraction $F(t) > \phi^*$ to adopt technology V_1, she will be more likely to adopt V_1 as well; if she expects more than $(1-\phi^*)$ to adopt technology V_2, she will be more likely to adopt V_2. The dynamics described by equation 1 has two stable rest points $F(t)=0$, $F(t)=1$ and an unstable one $F(t)=\phi^*$.

To see the relevance of the critical mass ϕ^*, suppose that V_2's critical mass is 0.2 and V_1's critical mass is 0.8. To topple the equilibrium in which everyone adopts V_1 requires only an initial fraction 0.2 of people to adopt V_2, whereas to move from a population of V_2 users to one of V_1 users would require more than 0.8 of initial adopters. It is reasonable to assume that a diffusion agent will find it easier to move the population over the critical mass in the first case than in the second.

Witt's main claim is that this result can be used to prove that "better technologies" (those with high values of $\pi(V_i,V_i)$) will tend to displace less efficient alternatives. However, this result has a general validity only in the particular situations in which the payoffs off the main diagonal are not truly relevant, because the two technologies satisfy the requirement of *perfect two-way compatibility,* that is $\pi(V_1,V_2)=\pi(V_2,V_1)$. One can easily show that in this case the superior technology has always a smaller critical mass.

However, the following proposition shows that when perfect two-way compatibility is dropped, it is not necessarily true that superior technologies have smaller critical masses.

Proposition 1 *When $\pi(V_1,V_2)\neq\pi(V_2,V_1)$, the efficient technology V_2 will have a smaller critical mass than V_1 iff $\pi(V_2,V_2)-\pi(V_1,V_1)>\pi(V_1,V_2)-\pi(V_2,V_1)$*

Proof. This is a simple consequence of the definition of the two critical masses ϕ^* and $(1-\phi^*)$ ■

3 Compatibility and critical mass as a strategic choice

So far I have treated compatibility (represented by the parameters off the main diagonal in the game in Table 1) as an inherent technological feature of the two technologies involved. However, in many circumstances the compatibility between technologies can be reduced or increased by decisions made by firms sponsoring them (see David and Bunn [3]). Increased compatibility is mostly achieved through *converters*. Familiar examples of converters are: computer programs that convert data from one format to another, two-way plugs that allow electric appliances sold in England to be plugged into the Italian electric network, and so on.

Formally, a *converter* is a pair $m = \{m_1, m_2\}$, with $m_i \in [0, 1)$. An agent adopting technology V_i *and* the converter, when interacting with an agent adopting V_j, gets a fraction m_i of the payoff she gets in her interactions with other agents adopting V_i. At the same time, the agent adopting V_j (without the converter) gets a fraction m_j of the full payoff she would have gotten in an interaction with another V_j adopter.

I will take as a starting point the situation in which, without converters, the two technologies are totally incompatible, so that $\pi(V_1, V_2) = \pi(V_2, V_1) = 0$. Suppose that a converter $m = \{m_1, m_2\}$ is embedded in one of the two technologies, so that an agent adopting that technology will automatically adopt the converter as well. The new game will look like the one represented in Table 2. Notice that the converters are two-way (partially) compatible in the sense that even if a converter is attached to one technology only, say V_1, it also affects the payoff of an agent who has technology V_2.

	V_1	V_2
V_1	$\pi(V_1, V_1)$	$m_1\pi(V_1, V_1)$
V_2	$m_2\pi(V_2, V_2)$	$\pi(V_2, V_2)$

Table 2: Technolgy adoption with converters

Converters are usually less than perfect because each technology performs poorly when forced to work together with another, formerly incompatible, technology. (Farrell and Saloner [5].) This is why we have assumed that $m_i < 1$. However, since we assume that $\pi(V_2, V_2) > \pi(V_1, V_1)$, even an imperfect converter can make the choice of the superior technology V_2 a dominant strategy. This is the content of the following:

Proposition 2 *When $\pi(V_2, V_2) > \pi(V_1, V_1)$, if $m_2 > \bar{m}_2 \stackrel{def}{=} \frac{\pi(V_1,V_1)}{\pi(V_2,V_2)}$, then the game in Table 2 has a single Nash equilibrium (V_2, V_2) with dominant strategies.*

Proof. If $m_2 > \frac{\pi(V_1,V_1)}{\pi(V_2,V_2)}$, then $\pi(V_2, V_1) = m_2\pi(V_2, V_2) > \pi(V_1, V_1)$. Since $\pi(V_2, V_2) > \pi(V_1, V_1)$, technology V_2 now yields a larger payoff than V_1 under all of the opponent's strategies. ■

Suppose that a converter m can be produced at a given cost. The innovation agent sponsoring V_2 will decide which converter to produce (if any), so that people adopting V_2 will also adopt that particular converter. I will say that the innovation agent *supports* a given converter m if there is a minimum cost below which he will produce m. Intuitively, the innovation agent supports a converter if he would be willing to produce it at least when it could be done without cost.

The innovation agent can be assumed to support a given converter if (and only if) that converter reduces the critical mass of the new technology he sponsors. This yields the following:

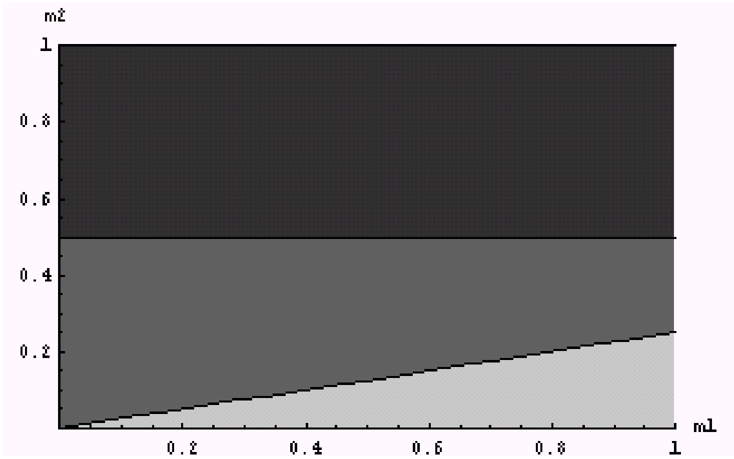

Figure 1: The innovation agent favors all converters with the exception of those placed in the lightest area. Converters placed in the darkest area create a null critical mass for technology V_2.

Proposition 3 *The innovation agent supports any converter* (m_1, m_2) *so that*

$$m_2 > \left(\frac{\pi(V_1,V_1)}{\pi(V_2,V_2)}\right)^2 m_1 \tag{3}$$

Proof. Before any converter is produced, the critical mass of technology V_1 is $\phi^* = \frac{\pi(V_2,V_2)}{\pi(V_1,V_1)+\pi(V_2,V_2)}$. Let $\phi(m)$ indicate V_1's critical mass after the introduction of converter $m = \{m_1, m_2\}$, $\phi(m) = \frac{\pi(V_2,V_2)-m_1\pi(V_1,V_1)}{\pi(V_1,V_1)(1-m_1)+\pi(V_2,V_2)(1-m_2)}$. The innovation agent will favor m iff $\phi(m) > \phi^*$, that is if the converter reduces the critical mass of technology V_2 $1-\phi^*$. Equation 3 can be obtained through elementary algebraic manipulation from

$$\phi(m) = \frac{\pi(V_2,V_2) - m_1\pi(V_1,V_1)}{\pi(V_1,V_1)(1-m_1) + \pi(V_2,V_2)(1-m_2)} > \frac{\pi(V_2,V_2)}{\pi(V_1,V_1)+\pi(V_2,V_2)} = \phi^* \tag{4}$$

■

Figure 1 illustrate Condition (3) for the numerical example $\pi(V_1,V_1) = 2$ and $\pi(V_2,V_2) = 4$, so that $\phi^* = \frac{2}{3}$. Converters in the darkest area fulfill the condition $m_2 > \bar{m}_2$, which makes

V_2 a dominant strategy. Converters in the lightest area fulfill the condition $\phi(m_1, m_2) < \phi^*$, so that they are not favored by the innovation agent. In between all converters are placed that reduce technology V_2's critical mass, although they do not eliminate it altogether.

There are at least two consequences of Proposition 3 that are worth stressing. *First*, the innovation agent is sympathetic toward compatibility. It is a direct consequence of Proposition 3 that he favors any two-way converter (for which $m_1 = m_2$) and even asymmetric converters more favorable to technology V_1 ($m_1 > m_2$), provided that condition (3) is met. *Second*, the availability of converters does not necessarily facilitate a transition to a superior technological standard. For instance, suppose that both the new and the old technologies are sponsored, so that there are *two* firms who stand to gain if their standard prevails. Suppose also that due to technical reasons, only a one-way converter $(m_1, 0)$ with $m_1 > 0$ can be produced. Such a converter will obviously reduce the critical mass of technology V_1, while increasing the critical mass of V_2. The firm sponsoring V_1 will contemplate producing such a converter in an attempt to prevent V_2 from reaching its critical mass, and this will make the transition to V_2 less likely. In this case, more compatibility translates into fewer chances of a successful transition even in the presence of a superior alternative.

4 Conclusions

The result obtained in Section 3 shows that, contrary to the original claim put forward in Witt [9], a superior technology needs not have a smaller critical mass than a less efficient alternative. As a consequence, an established technological standard is more seriously challenged by an inefficient alternative which is highly compatible with it, rather than by a highly superior technology which is totally incompatible with it. It follows that compatibility between competing technologies plays a decisive role in any successful transition, which is not less important than the role played by their relative efficiency. I have also shown that the "diffusion agent" is induced to manipulate the technology he sponsors in order to make it more compatible with the existing standard, even when this might reduce its performances.

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