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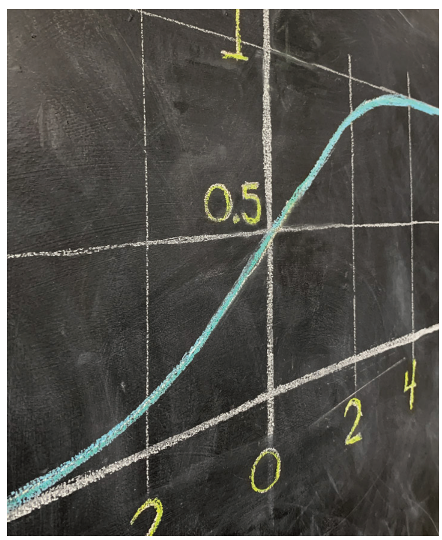
The Profession of IT
Technology Adoption

The S-shaped curve of technology adoption is a welcome recurrence in an otherwise chaotic adoption world.

TECHNOLOGY ADOPTION IS accelerating. The telegraph was first adopted by the Great Western Railway for signaling between London Paddington station and West Drayton in July 1839, but took nearly 80 years to peak (1920).[a] The landline telephone took 60 years to reach 80% adoption, electric power 33 years, color television 15 years, and social media 12 years.[b] The time to adoption is rapidly decreasing with advances in technology.

When we develop new technology, we would dearly like to predict its future adoption. For most technologies, total adoptions follow an *S* curve that features exponential growth in number of adopters to an inflection point, and then exponential flattening to market saturation. Is there any way to predict the *S* curve, given initial data on sales?

Technology adoption means that people in a community commit to a new technology in their everyday practices. A companion term diffusion means that ideas and information about a new technology spread through a community, giving everyone the opportunity to adopt. Adoption and diffusion are not the same. Here we are interested in adoption as it is manifest in sales of technology. Adoption models attempt to estimate two quantities that affect business decisions whether to produce technology. One is the total addressable market *N*, the number of people who will ultimately adopt. The other is t^*, the time of the inflection point of the *S* curve.



It would seem that to develop a model of the *S* curve we would need a model of the underlying process by which technology is produced and sold. Three process models are common:

- *Pipeline*: an idea flows through the stages of invention, prototyping, development, marketing, and sales, finally being incorporated into the marketplace as a product people buy.
- *Funnel*: similar to pipeline but the pipeline begins with multiple ideas and each stage winnows the number passed to the next stage until finally one product emerges into the marketplace. This model aims to compensate for the high failure rate of ideas. If failure rate is 96% (a common estimate), the funnel-pipeline must be seeded with 25 ideas so that there will be one survivor to the final stage.
- *Diffusion-Adoption*: ideas are treated as innovation proposals that spread through a social community, giving each person the opportunity to adopt it or not.

Unfortunately, there are important innovations that are not explained by some or all of these models. For example, spontaneous innovations do not follow the pipeline or funnel models, and many diffusions do not result in adoption. Moreover, the models are unreliable when used as ways to organize projects—they explain what happened in the past but offer little guidance on what to do in the immediate future. Many organizations manage their internal processes according to one of these models. People in these organizations frequently experience a "Fog of Uncertainty" when something unanticipated comes up in one of the stages and it is not obvious what to do.

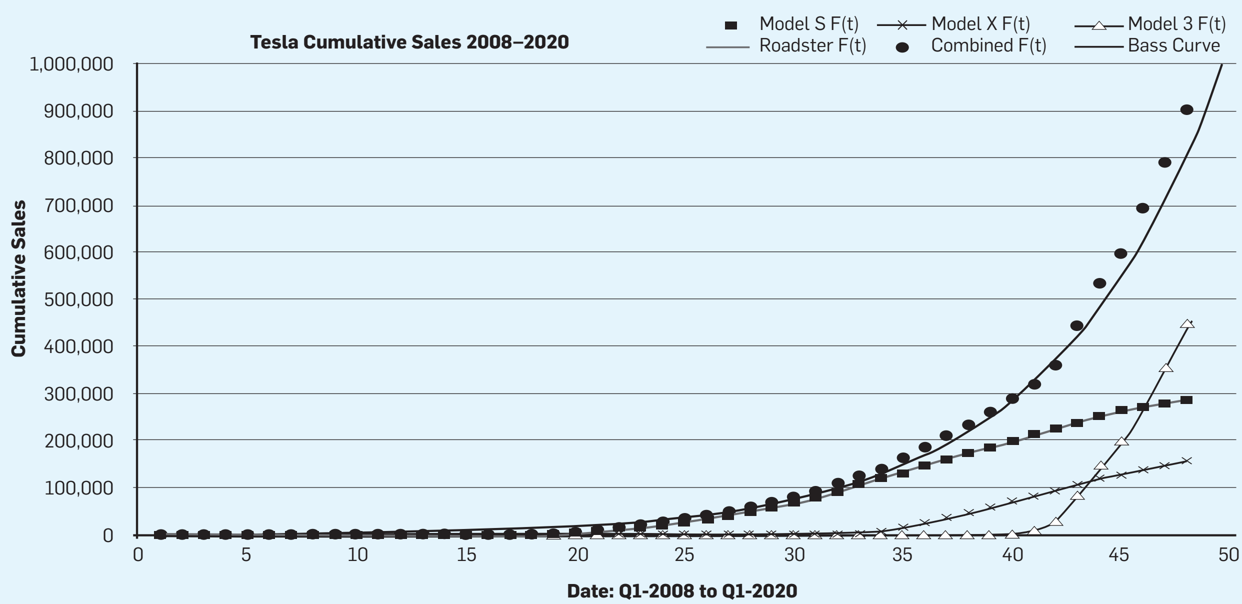
Insight from the Diffusion Model

The defects in pipeline models brought much attention to Everett Rogers' diffusion model, first introduced in 1962.[5] Rogers' diffusion model explicitly recognizes social interactions in technology adoption. Neither the pipeline nor funnel models gives a role to social preferences in the adopting communities. The diffusion model postulates that individuals in the community receive information through their social networks that enables them at some point to decide to adopt the technology.

Rogers observed that each individual in a community takes a different time to adopt. He found that the statistics of time-to-adoption follow

a See https://en.wikipedia.org/wiki/Telegraphy#Electrical_telegraph
b See https://ourworldindata.org/technology-adoption

Figure 1. Cumulative quarterly sales of Tesla products from 2008 to 2020 and the Bass *S*-shaped curve fit for combined cumulative sales.



a Bell curve. On a Bell curve 68% of adoptions are within one standard deviation *S* of the mean adoption time T. Rogers labeled those adopters "the majority." He also labeled the 12.5% of adopters in the band from T-2S to T-*S* the "early adopters" and those in the 2.5% band above T+2S the "laggards" who will never adopt. His key insight was to connect these bands of the Bell curve with dispositions of community members toward adopting a proposed innovation. From many interviews, Rogers confirmed that the early adopters are disposed to adopt quickly, whereas the majority are disposed to wait until the technology is widely adopted, trustworthy, and reliable. And the laggards are disposed against any innovation.

An important insight from these distinctions is that the company needs a different appeal for early and majority adopters. In 1991, Geoffrey Moore explained many start-up business failures by noting their initial business plans aimed at early adopters, and by the time they realized they saturated that market, it was too late to raise new capital to organize for the majority.[4] He advised business leaders, as a matter of survival, to anticipate the majority as part of their initial planning.

Thomas Edison is a famous historical innovation leader who understood this. Although he is often credited for inventing the light bulb, he did not begin to experiment with light bulbs until he saw a way to generate and distribute electricity. Without cheap in-home electricity, there would be few customers for light bulbs. In 1878, when he finally found a technology to generate and distribute electricity, he set his research staff searching for a light bulb that would last for days or weeks without burning out. The idea of a light bulb was about 60 years old by that time, but the bulbs that existed burnt out within a few minutes of being turned on.

Elon Musk is a modern business leader who understands the need to make offers for majority adopters. Even before the first Tesla electric car rolled off the assembly line, he said that without charging stations there would be few customers for electric cars. He invested in building a network of charging stations that would be available for the first Tesla drivers.

Novelty and Imitation

Rogers' early adopters respond to novelty. The newness of a technology and possibilities it offers are very attractive to them. In contrast, majority adopters are imitators. They will not adopt unless they see a sufficient number of others already doing so.[3]

The process of adopting by imitation is dominated by what complexity theorists call "preferential attachment." That means that an adopter may have choices between several technologies, or none at all. Imitation adopters will tend to line up with the option that seems to have attracted the biggest following—safety in numbers.

Complexity theory has established that a process dominated by preferential attachment has a power law distribution of times between adoptions. The power law distributions observed in practice have no finite means or standard deviations. That means that traditional statistical methods of predicting the time till next event, or the number of events in a time interval, all fail.[2] This puts project leaders into a bind: they cannot use standard statistical methods to predict how successful the future adoptions of their technology will be.

Results for Bass model and projections.

Parameter	Roadster	Model S	Model X	Model 3	Combined
p (innovate)	.0265	.0087	.0104	.0077	7 x 10-6
q (imitate)	0.9470	0.1556	0.2347	0.4042	0.1302
*t** (time to inflection, quarters)	3.67	17.56	12.70	9.62	75.43
N (total market)	1,896	311,185	234,736	808,361	43,402,353

Fitting Bass Equation to Data

The Bass model is an *S*-curve of total sales (adoptions) defined by this differential equation, where *s* and *S* are functions of time *t*:

$$s = \frac{dS}{dt} = (p + \frac{q}{N}S)(N - S)$$

Function *S* is the total sales. Function *s* is the rate of change of *S*, that is, the sales rate. Parameter *N* is the total size of market, that is, the maximum number of adoptions possible. Parameter *p* is the rate of spontaneous adoptions from non-adopters. Parameter *q* is the rate of imitation, that is, the rate at which each existing adopter attracts more adoptions.

The right side of the equation can be understood by separating it into two terms. The term $p(N\text{-}S)$ is the rate at which non-adopters spontaneously become adopters. The term $qS(1\text{-}S/N)$ is the imitation rate generated by current adopters (qS) throttled back by the fraction of market that has not yet adopted. The solution to this equation is

$$S(t) = N\frac{1 - e^{-at}}{1 + re^{-at}}$$

Where $a=p+q$ and $r=q/p$. This equation has starting value $S=0$ (initially no one has adopted) and final value for large time of $S=N$ (everyone has adopted). Its inflection point is $t^*=(\ln r)/a$.

The right side of the Bass equation can be re-expressed as a quadratic equation,

$$s = Np + (q - p)S - \frac{q}{N}S^2$$

This can be interpreted as the quadratic form

$$s = A + BS + CS^2$$

where $A = Np$ and $B = q\text{-}p$, and $C = \text{-}q/N$. This form is very useful for fitting the model to data because the available data are usually in the form of sales rate versus total sales, that is, *s* versus *S*. Using a least-squares fitting algorithm we can find *A*, *B*, and *C* that give the least error fit of the right side of this quadratic form with the data. The total market *N* is unknown but can be estimated from the data as follows. When the quadratic form for *s* is 0, there can be no growth of *S*. The solutions of the corresponding quadratic equation are:

$$S = \frac{-B \pm \sqrt{B^2 - 4AC}}{2C}$$

Thus s=0 when *S* is either of the values

$$S = N \quad and \quad S = -\frac{Np}{q}$$

Since negative sales are of no interest, the positive root of the quadratic form gives us the estimate of *N*. Then

$$p = \frac{A}{N} \quad and \quad q = B + \frac{A}{N}$$

Thus, the model parameters *p*, *q*, and *N* can be estimated from the data.

The Bass Model

But all is not lost. Many studies of adoption processes have found that the number of adoptions over time follows an *S*-curve, irrespective of the innovation models managers espouse or chaos in the adoption process. The *S*-curve is a stable feature of almost all technology adoption processes. Is it possible to estimate the *S*-curve from its initial adoption data? If so, managers could estimate the saturation market and time to inflection.

In 1969 Frank Bass, a marketing analyst, came up with a model of the *S*-curve that had just two parameters that could be measured from initial adoption data. Bass's two parameters correspond to Rogers' early adopters and majority. Bass's first parameter p is that rate at which early adopters adopt spontaneously. His second parameter q is the rate at which the majority adopts by imitation. Bass defined a differential equation whose solution $S(t)$ is the expected number of sales (adoptions) by time t, given that the process began at time 0. When t is large, $S(t)$ levels off at N, the total market size; see the sidebar.

Let us illustrate with sales figures from Tesla Motors. We used the method of the sidebar to fit a Bass curve to the combined sales of all models since the beginning of Tesla. This yields p, q, and N. The result is shown as "Combined $S(t)$" in the figure here. Similar *S*-shaped curves are shown for all models. The accompanying table summarizes the values for p, q, t^*, and N. It is interesting to note that p is lowest for the Model 3, suggesting that conservative imitators are dominating sales of the Model 3. In the same period sales of the similarly priced BMW 3/4 series cars declined from 140,000 units to 66,000 units, suggesting that customers are preferentially attaching themselves to Tesla.

The adoption curves for Roadster, Model S, and Model X each take over when the previous one starts to sag. This suggests Tesla is engaging in technology jumping: as sales of one model peak and reach an inflection point, the next generation begins. When consumers jump to Model 3, sale of Model S and X decline.

Conclusion

But Bass's model is limited. It offers no guidance for project leaders on a day-to-day basis. How do they deal with unexpected contingencies? Factors that cause deviations from the business plan? Project leaders need to learn navigational skills to make it through these trials.[1]

The *S*-curve and its Bass model are a welcome recurrence in an otherwise chaotic adoption world. Because of this, the *S*-curve can be a very useful tool for businesses seeking to estimate the total size of their market and the time peak sales rate.

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