DECISION SCIENCES INSTITUTE

Diffusion in the Acceptance of Influenza Vaccination following the Pattern of Technology Adoption

Jesus A. Cardenas
University of Texas at El Paso
Email: jacardenas3@utep.edu

Leopoldo Gemoets
University of Texas at El Paso
Email: lgemoets@utep.edu

Michael L. Gonzales
University of Texas at El Paso
Email: mlgonzales2@utep.edu

ABSTRACT

The diffusion process for information technology devices seems to follow the Bass' diffusion model. We are trying to prove that this pattern is also applicable to preventive health technology for the Influenza vaccination. Using the diffusion of cell and smart phones, we support that acceptance of these technologies follows Bass' diffusion model, but once implemented, the evolution is driven by imitation more than innovation. For vaccination acceptance, the results show a pattern of innovation more than imitation, suggesting that acceptance of health preventive technology is still in the innovation stage with low maturity levels, as imitation has not started yet.

KEYWORDS: diffusion, prevention, influenza, Bass model, and maturity

INTRODUCTION

By the end of 2014, 6.9 billion people around the world were using mobile phones (UN Data, 2017). Launched in 1981 in Scandinavia, mobile phone service has become a part of everyday life for most of the world's population residing in 211 countries; Time magazine recently noted that more people have access to mobile phones than to toilettes (Wang, 2013). Moreover, in several developed nations, the mobile phone has reached a penetration level that some countries like Macao China have more than 322 phones per 100 inhabitants according to the numbers published by the World Bank. This represents that consumers have more than one phone, more than one phone number, more than one time card, and/or more than one service provider.

The period between the early 1990s can be regarded as the turning point in the telecom industry with the opening of a traditionally closed and de facto monopolistic, even in some cases government controlled market into a competitive one. This market liberalization movement has been forcing telecommunications industry and governments to shift from measuring production costs to the assessment of productivity. Some governments have been forced to develop or liberalize norms and policies for the information and communication technologies (ICT) sectors, so that they can invest large portions of their budgets in ICT.

The acceptance of mobile phones to data has been so overwhelmingly positive, that it is not strange to see people from remote regions using cell phones. The penetration in some countries such as Cuba and South Sudan has been slow, but Cuba has already over 24 phones per 100 inhabitants, and 2.5 million subscriptions (UN Data, 2017).

The purpose of this paper is to relate the process of technology acceptance of cell phones to the healthcare acceptance of influenza vaccination as a technology for prevention of illness. Both are technologies and as such, there are going to be categorized as groups of innovators accepting the technology before the mass implementation and deployment stages.

Wanting to know if the Bass' diffusion method had been previously applied to the health sector, we researched into the available peer-reviewed papers about health care and we were able to find a paper written in 1992 where the Bass' diffusion model was implemented for health care applications. From that time on, no other study like this has been conducted.

Progress in the use of vaccine technology may potentially prevent illness and also reduce the financial burden of diseases in future, although improving the outcome; healthcare industry is still facing problems in the short term (McCulers & Dunn, 2008).

Interestingly, studies suggest that Millennials are more prone to accept technology that older people, so our expectation would be that younger inhabitants would accept more readily the introduction of the influenza vaccination than older people.

TECHNOLOGY DIFFUSION

This section of the paper represents the Bass model for a single series. Using the extension of the basic diffusion model (Bass, 1969) we implement non-linear squares, under the assumption that errors have the same variance throughout the time series. In order to overcome that constraint, Boswijk and Frases (2005) borrow from financial econometrics to propose a stochastic error process modified for the Bass model. The approach is developed to capture heteroscedasticity errors and a tendency for the data to revert to the long-term trend. Additionally, this model includes an additional regressor and is that we rely on simulated maximum likelihood to estimate the parameters.

The first developed Bass model originally stated that the probability of the adoption of an innovation — given that the individual has not adopted it yet — it is linear with respect to the number of previous adopters. The model parameters p, q, and m can be estimated from the actual adoption data.

Following the representation as advocated in Boswijk and Franses (2005). We discuss the multi-level model for a panel of diffusion series. Finally, we report the parameter estimation of this last model.

The Bass model assumes a population of m potential adopters, where, in the context of our research, we will associate m with the maximum number of individuals who could adopt the technology. In our context, adopters should be viewed as individuals who adopt the cited technology. The maturity level can be viewed as the total number of people who could receive the technology in the long run. For each adopter, the time to adoption is a random variable with a distribution function $F(t)$ and density $f(t)$, such that the hazard rate equals

$$\frac{f(t)}{1 - F(t)} = p + q\,F(t) \qquad (1)$$

where p and q are the parameters that determine the shape of the diffusion process. The cumulative number of adopters at time t, denoted by N(t), is a random variable with mean

$$\bar{N}(t) = E\,[\,N(t)\,] = m\,F(t) \qquad (2)$$

where t is measured in continuous time and E denotes the expectation operator. It can be shown that the function N-bar(t) obeys the following differential equation, that is

$$\bar{n}(t) = \frac{dN(t)}{dt} = p[\,m - \bar{N}(t)] + \text{—}\,\bar{N}(t)\,[\,m - \bar{N}(t)] \quad \text{*see Bass (1969).} \qquad (3)$$

In the new technology diffusion literature, it is common to interpret the parameter p as the innovation parameter, q as the imitation parameter, and m as the maturity or saturation level. Note that these parameters exercise a non-linear impact on the pattern of N-bar(t) and n-bar(t). Basic characteristics of the diffusion also non-linearly depend on p and q. For example, the inflection point T* of F(t), which corresponds with the time of peak adoptions, equals

$$T^*=[1/(p+q)]\,\log(q/p) \qquad (4)$$

A natural question is now how one can translate the theoretical model in (1) into an empirical model with parameters that can be estimated using actual discrete-time data. Bass (1969) proposes to use the cumulative number of adoptions in discrete time (N_t, for t= 0, 1, 2,…,T) and the corresponding increments ($X_t=N_{t-N}(t-1)$), and to consider the regression model

$$X_t=pm+(q-p)\,N_{t-1} -(q/m)\,N_{t-1}^2+\varepsilon_t \qquad (5)$$

where t =1,…,T refers to a time series measured at discrete intervals. Bass (1969) further assumes that ε_t is a standard white noise error term.

Using some secondary sources of data about the acceptance of technology by race and ethnicity, we researched some data to conduct the diffusion study using the Bass model. To review acceptance of technology, we are going to use the mobile phone acceptance by the sectors of the USA population.

While analyzing the World Bank data (2017) we discovered that the latest statistics reported for 2014 is 107 subscriptions per 100 inhabitants in the United States, and the estimated number from the CIA World Factbook (2017) is 114 subscriptions per 100 inhabitants. Using the Bass diffusion formula (1), we obtained the results shown on Table #1.

	Cum level	Maturity Level (m)	Innovation Index (p)	Imitation Index (q)	Diffusion Speed
Cell phones (M)	355.50	354.23	0.0020	0.241	117.88
Whites (%)	91.00	123.75	0.0146	0.081	5.55
Blacks (%)	94.00	96.41	0.0000	0.476	47,553
Hispanics (%)	92.00	96.34	0.0001	0.356	3,358

Table 1. Diffusion Statistics for the Cellphones Ownership by Races in the USA

The diffusion curve is showing that the innovation factor is smaller than the imitation factor, so the growth of the technology acceptance is very much based on imitation among peers and friends, and the maturity level is almost reached, because there are 355.5 million cellular phone subscriptions in the USA with a population of 322,761,807 as calculated for January 1, 2016 in the USA Census populations clock (www.census.gov/popclock/). Breaking down the acceptance of technology by ethnicity and races, we discovered that white people are the ones with the highest innovation factor, representing the leaders of acceptance of this innovation, although Black people are the one with the highest imitation factor, and in such a way that they have almost completed the diffusion of cell phones. Hispanics are showing a mid-point on the imitation, while the innovation index is very small, in other words, Hispanics are not taking risks accepting technologies, but once they feel confident, they go for it very quickly.

Figure # 1: Calculated Bass diffusion curve for Cell Phones using (World Bank Data, 2017

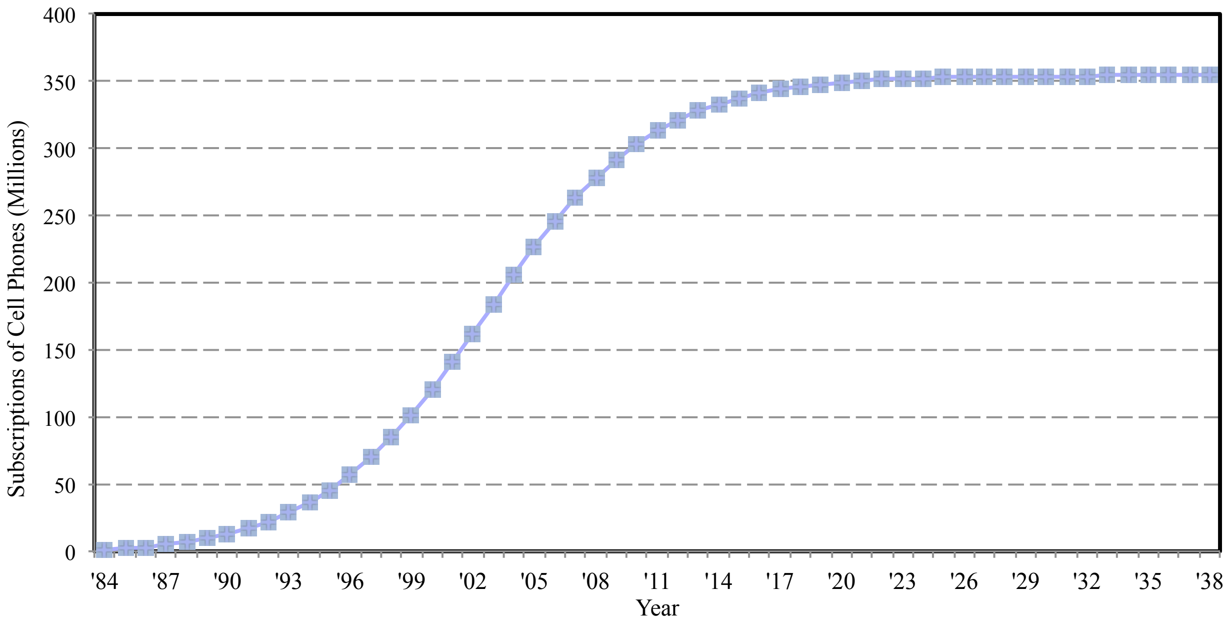
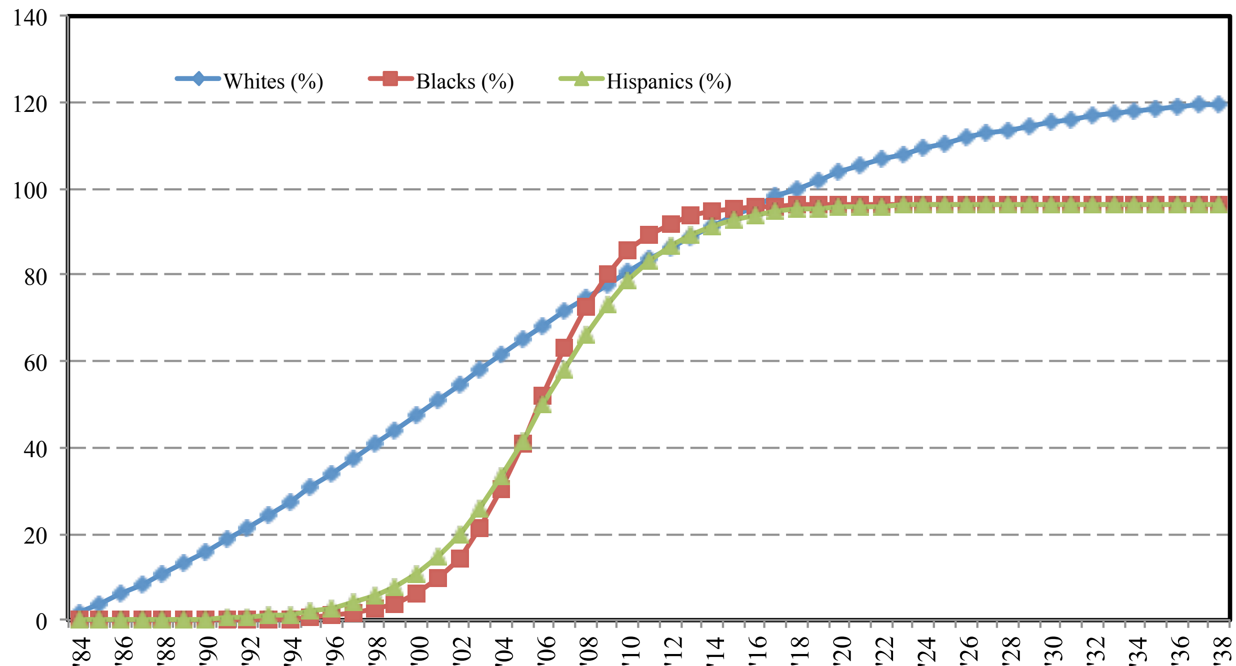


Figure #2 shows the diffusion of cell phones for white people going steadily until 2038, when the maturity of the diffusion will be completed, but for Black and Hispanic populations, the diffusion of cell phones is almost completed at this time because their imitation factor is so high. We can conclude that white people include the group of risk-takers on technology that are the innovators implementing cellular telephony, but after this group, the rest of the population is cautious about the imitation. For the Hispanics and Black population groups, we see that they are not typically innovators, but once that others have accepted the technology, the imitation factor is very high and that drives the diffusion curve very quickly to maturity.



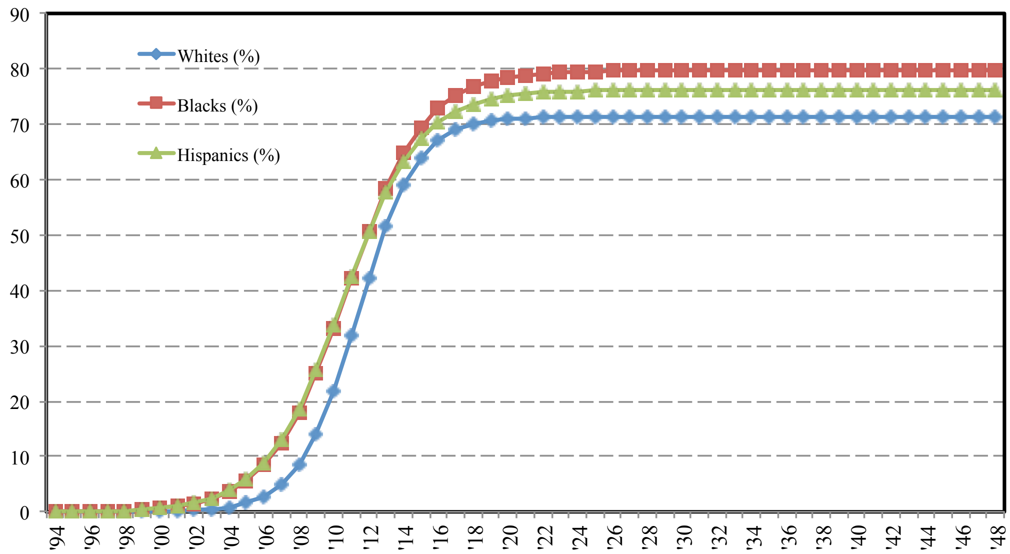
Cell phones have now evolved into phones that have computer functions and can do many other tasks, aside of being a telephone. This new brand of phones is identified as smartphones, which have become a technology challenge for many of the users. Researching, we can see that the smartphone diffusion has been growing rapidly, but following a different pattern than the cell phone. By 2015, 68% of all adults have a smartphone that allows them to access the Internet. Using the same analysis we are finding that the diffusion curve shows that the innovation factor is smaller than the imitation factor, so the growth of the technology acceptance is very much based on imitation among consumers who already had a cellular phone and have evolved to a more technologically advanced smart phone, and the maturity level will be reached very soon.

Table #2: Diffusion Statistics for the Smartphones Ownership by Races in the USA

	Cum level	Maturity Level (m)	Innovation Index (p)	Imitation Index (q)	Diffusion Speed
Smartphones (%)	68.00	92.28	0.0004	0.3570	964
Whites (%)	66.00	71.33	0.0000	0.5944	55,489
Blacks (%)	68.00	79.67	0.0002	0.4504	2,974
Hispanics (%)	64.00	76.16	0.0002	0.4507	2.654

Breaking down the acceptance of technology by ethnicity and races, we discovered that white people were the ones with the lowest innovation factor, representing Blacks and Hispanics as the leaders of acceptance of this innovation. White population is the group with the highest imitation factor, which is followed closely by Hispanics and Blacks, but the maturity level is a little bit higher for Blacks. Hispanics and Blacks are not slower accepting technologies, but once they feel confident, they implement them very quickly. Figure #3 shows the diffusion of smartphones is going steadily until 2018, when all groups will be reaching the expected maturity of the diffusion of around 80%.

Figure 3. Bass' Diffusion Growth for Smartphones Ownership (Pew Research Center)



INFLUENZA VACCINATION

As shown in the past section, the Bass diffusion curve can represent the acceptance of technologies such as cell phones, so we now are going to equate vaccination to technology of treatment in a way that we expect the acceptance of vaccination to follow the Bass' Diffusion model curve.

Researching into the data available in the Center for Disease Control and Prevention in the page for the seasonal influenza vaccine total doses distributed and considering all data from 1980 from the Centers for Disease Control and Prevention (http://www.cdc.gov/flu/professionals/vaccination/vaccinesupply.htm), we input those numbers into the Bass diffusion formula to calculate the rate of diffusion and the results are shown in Table # 3.

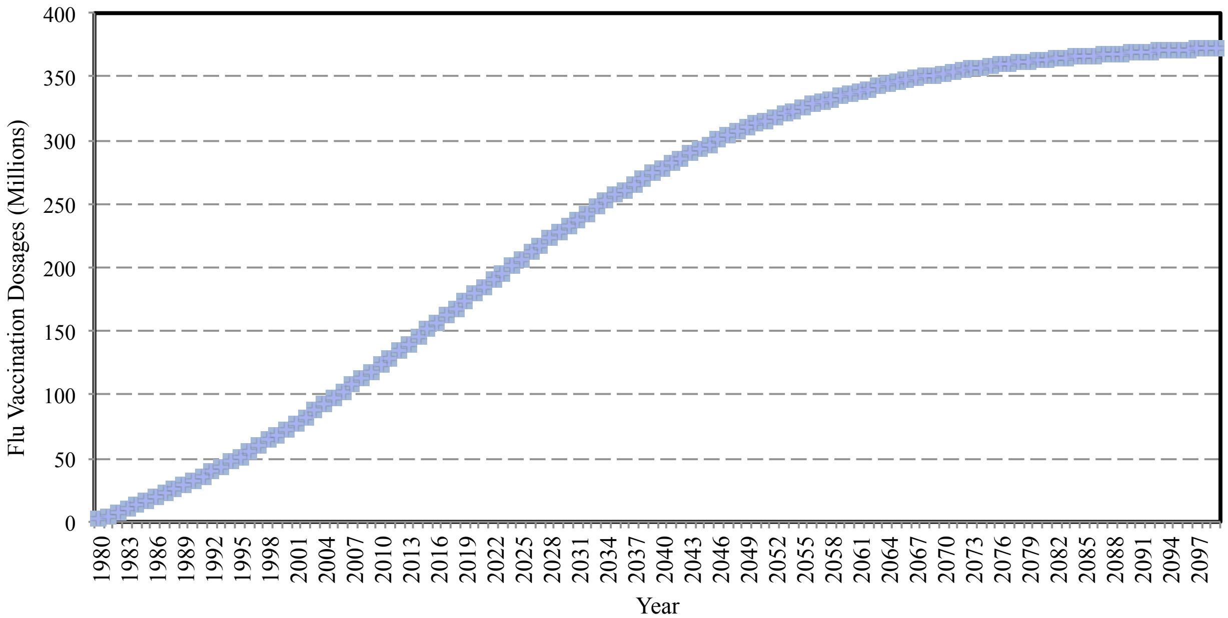
Table 3. Diffusion Statistics for the Influenza Vaccines Doses Distributed in the USA

	Cum level (millions)	Maturity Level (m)	Innovation Index (p)	Imitation Index (q)	Diffusion Speed
Influenza Vaccine	148	378	0.0063	0.0459	13.6

The results show that the maturity level could be reached at 378 million doses, which will probably be equivalent to the whole population of the USA. The innovation index is smaller than the imitation index, therefore, the diffusion was heavily influenced by imitation very quickly as the diffusion speed is 13.6 the imitation index greater than the innovation index.

Putting these results in the diffusion curve, we can see that the diffusion of the vaccination will continue growing steadily, although there are no expected big jumps on acceptance overnight as the growth is almost linear and it is expected this way until probably 2055.

Figure 4. Bass' Diffusion Growth for Influenza vaccination (Centers for Disease Control)



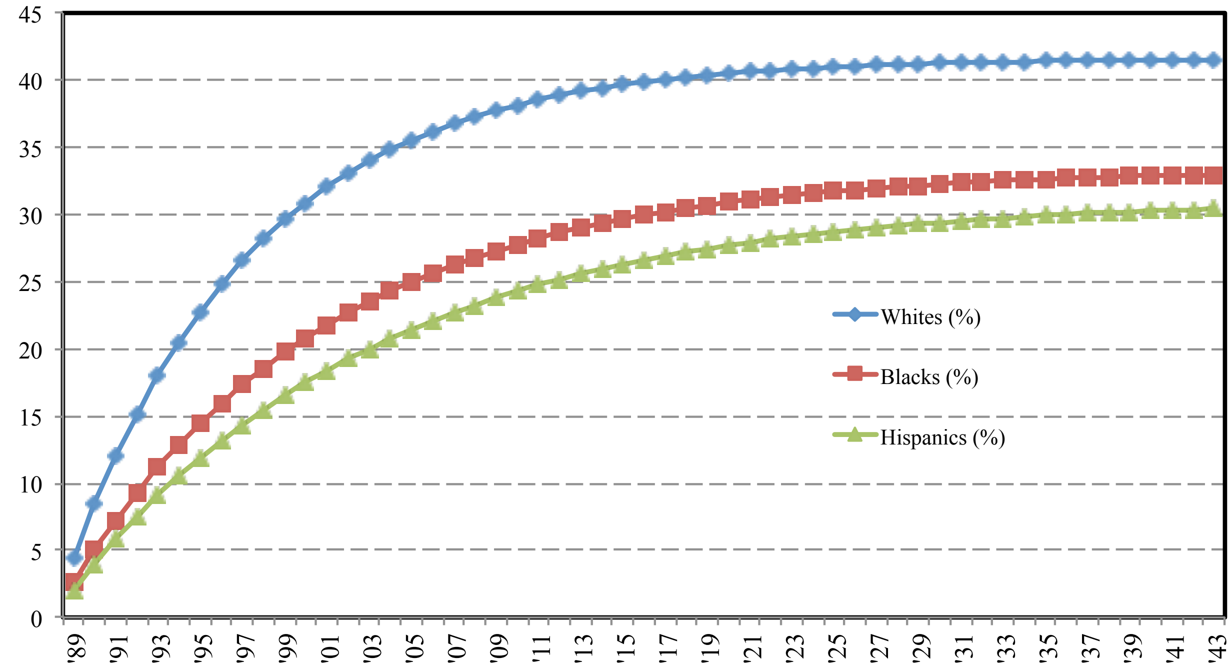
Using the National Center for Health Statistics trends table #4 we used the data to identify is there is any difference on the diffusion of the vaccination acceptance for the races and groups that we monitored for cell phones. The variables used for this table are percentages of the population that are receiving vaccinations, and the results show that the imitation index is zero at all cases, that is the diffusion curve is moved by the innovation index only. Hispanics are the slower ones accepting the vaccination while the Black population is faster on acceptance, and Whites are the fastest of all.

Table 4. Diffusion Statistics for the Smartphones Ownership by Races in the USA

	Cum level	Maturity Level (m)	Innovation Index (p)	Imitation Index (q)	Diffusion Speed
Flu Vaccination (%)	42.20	37.71	0.1143	0.0000	0
Whites (%)	46.00	41.61	0.1129	0.0000	0
Blacks (%)	34.40	33.36	0.0813	0.0000	0
Hispanics (%)	31.00	31.16	0.0687	0.0000	0

Because the innovation index is the one driving the curves, they seemed to have reached the maturity level already, although the expectation is that the percentage of penetration will go much higher once that the technology is accepted by the population.

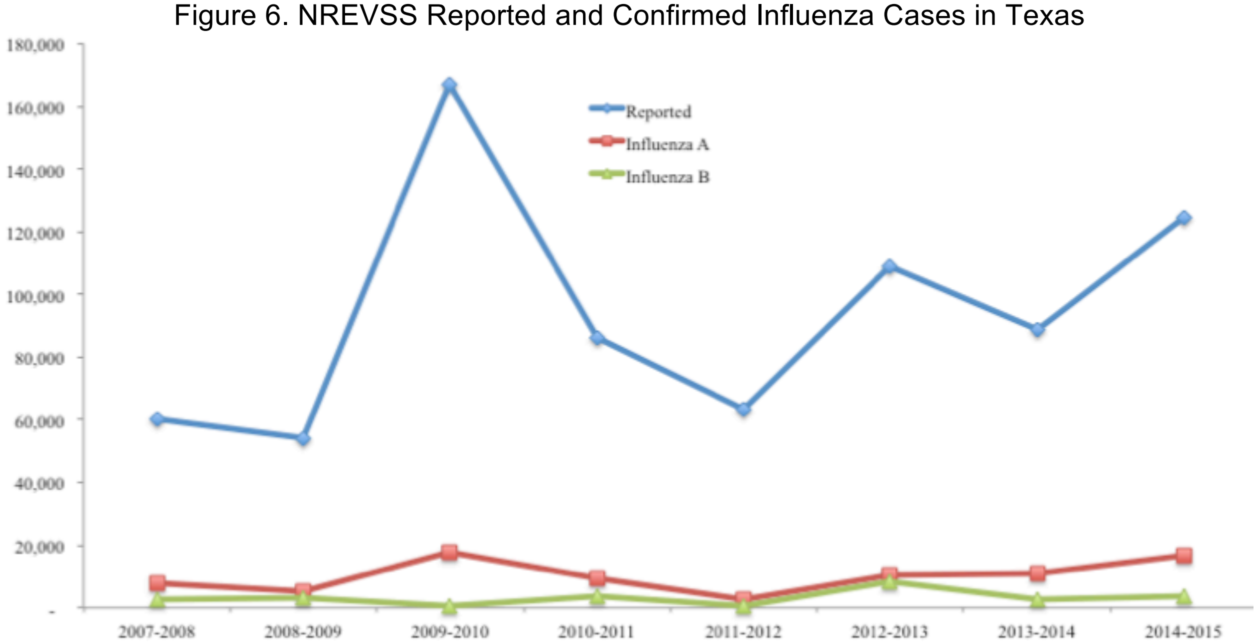
Figure # 5: Bass' Diffusion Growth for Influenza Vaccination Penetration (%)



VACCINE RESULTS

Collecting the data that shows the number of confirmed cases of Influenza in Texas, as reported by National Respiratory and Enteric Virus Surveillance System (NREVSS), we can see an upward trend of reported cases as well as Influenza A confirmed cases, but the Influenza B cases seem to be stagnant at a lower level.

Figure 6. NREVSS Reported and Confirmed Influenza Cases in Texas



The majority of people (73.87%) receiving the vaccination are white, while the population percentage for that group is 63.05%; we can see in the data that the percentage of white population in the United States is reducing continuously as shown in Table 5, as the vaccination percentage is also reducing. The same behavior can be observed for the Black only population, which is also decreasing its percentage population wise, and in participants of the vaccination. The most aggressive growth comes from the Hispanic population.

Table 5. Vaccinations and Population (older than 6 months) Proportions

	Vaccination Percentage				Population Percentage			
	'11-'12	'12-'13	'13-'14	'14-'15	'11-'12	'12-'13	'13-'14	'14-'15
White only (%)	76.05%	75.16	74.29%	73.87%	64.32%	63.93%	63.56%	63.05%
Black only (%)	8.93%	8.88%	8.40%	8.28%	13.7%	13.76%	13.82%	13.90%
Hispanic (%)	8.28%	8.73%	10.05%	10.23%	16.70%	16.89%	17.10%	17.37%
Multiple race (%)	6.73%	7.22%	7.61%	7.61%	5.28%	5.41%	5.52%	5.68%

CONCLUSION

The consumers who are intrepid and adventurous accept new technologies; they are identified as the innovators. In the case of cell phones, this was a new technology that was accepted by white innovators first and then the other groups followed suit, but once that the cell phone evolved into a smartphone, the imitation factor is larger and the innovation factor is almost zero. This means that the evolution of technology is more easily imitated than original new technology. When we bring these conclusions to the Influenza vaccination, we are finding that it is at the early stage where the curves are driven mostly by innovators that slowly but surely are increasing the acceptance of the technology to a maturity level that it is low at this time, but we are expecting that the curve will jump up as more people accept the vaccination by imitation. The white population has been the leader on innovation while accepting technology, but with the vaccination we are seeing an important increase of Black and Hispanic population that will probably become the example to follow for the imitators or early adopters.

REFERENCES

Bass, F. 1969. "A new product growth model for consumer durables". Management Science (15:5), pp. 215–227. doi:10.1287/mnsc.15.5.215.

Boswijk, H. P., and Franses, P. H. 2005. “The Econometrics of the Bass Diffusion Model”. Journal of Business and Economic Statistics, (23:3), pp. 255-268

CIA World Factbook, 2017. https://www.cia.gov/library/publications/the-world-factbook/geos/us.html

Desiraju, R., Nair, H., and Chintagunta, P. 2004. “Diffusion of new pharmaceutical drugs in developing and developed nations,” International Journal of Research in Marketing, (21:4), pp. 341−357.

Donegan, M., and Lunden, I. 2004. “G-men crash the mobile payment party,” Total Telecom Mag. (June 2004), pp. 20–22

Garrido, Elizabeth A., 2011. “6.5 Million Cellphones for 3.4 Million People,” La Prensa.com January 6, 2011

McCullers, J. A., and Dunn, J. D. 2008, “Advances in Vaccine Technology And Their Impact on Managed Care”, Pharmacy & Therapeutics, Jan; 33(1), pp. 35-38, 41.

UN Data. 2017. “Mobile-cellular telephone subscriptions” (http://data.un.org/Data.aspx?q=mobile&d=ITU&f=ind1Code%3aI271)

Wang, Y. 2013. “More People Have Cell Phones Than Toilets, U.N. Study Shows,” Time Magazine. March 25, 2013

World Bank Data, 2017. http://data.worldbank.org/indicator/IT.CEL.SETS.