

Characterizations of Deployment Rates in Automotive Technology

Stephen Zoepf and John Heywood
 MIT

ABSTRACT

Passenger cars in the United States continue to incorporate increasing levels of technology and features. However, deployment of technology requires substantial development and time in the automotive sector.

Prior analyses indicate that deployment of technology in the automotive sector can be described by a logistic function. These analyses refer to maximum annual growth rates as high as 17% and with developmental times of 10-15 years. However, these technologies vary widely in complexity and function, and span decades in their implementation.

This work applies regression with a logistic form to a wide variety of automotive features and technologies and, using secondary regression, identifies broader trends across categories and over time. Developmental time, measured as the time to reach maximum growth, has declined exponentially and now stands at approximately ten years, although individual manufacturers have demonstrated the ability to implement technology more quickly than industry averages. While required safety features and emissions control technologies achieve faster deployment rates than optional features, there is not a clear casual relationship between an early requirement and rapid growth rate.

The ability to develop and deploy technology quickly will be critical to meeting future fuel economy regulations. Technology deployment levels modeled in 2017 CAFE regulations fall broadly within the range of historical norms, but several specific technologies exceed historical application rates for non-safety applications.

CITATION: Zoepf, S. and Heywood, J., "Characterizations of Deployment Rates in Automotive Technology," *SAE Int. J. Passeng. Cars - Electron. Electr. Syst.* 5(2):2012, doi:10.4271/2012-01-1057.

INTRODUCTION

For nearly a century the automobile has been the dominant form of personal transportation in the United States. During its development over the past century the passenger car has evolved from a rudimentary, self-propelled "horseless carriage" to a sophisticated device capable of traveling hundreds of miles at high speeds. However, such marginal improvement in vehicle functionality can be better characterized as the product of the independent development of hundreds of individual technologies. All new vehicles sold in the United States incorporate seat belts and at least two airbags; virtually all new vehicles include air conditioning and automatic transmissions; many also include navigation systems, moonroofs and a bevy of other electronic aids. Other technologies that improve the performance, safety and efficiency of vehicles are unnoticed by the typical buyer but have evolved along similar patterns.

A wealth of literature has been published on the diffusion of innovations in various markets. One of the most commonly cited of these, the Bass diffusion model, uses counterbalancing feedback loops of market saturation and

word of mouth communication create the familiar S-shaped curve seen in diffusion models.

In this work a least-squares regression with a logistic form has been applied to feature take rates for passenger cars (light truck vehicles are not considered here) gathered from EPA Fuel Economy Trends reports, Ward's Factory Installed data and U.S. DOT report HS 809 834. The functional form of the regression used in this analysis is as follows:

$$TakeRate(t) = Limit / (1 + \alpha e^{-\beta t}) \quad (1)$$

Where α is a parameter primarily impacting lag and the β parameter describes the steepness of the curve.

Prior Work

DeCicco (2010) applies regression with a logistic form to feature take rate data available from EPA for front-wheel drive, fuel injection, multivalve engines and VVT. The analysis proposes a logistic function and discusses both the steepness parameter of the adoption curve and also the number of years since the first significant use. DeCicco also proposes a logistic function within the range of other

powertrain technologies as a plausible deployment scenario for hybrid electric vehicles (HEVs).

While [Kramer and Haigh \(2009\)](#) do not use the term “logistic function,” the authors use descriptive language to identify phases of growth in the power generation sector that are remarkably similar to those seen in the automotive industry. Kramer and Haigh also discuss the importance of the developmental phase of new technology, citing that it takes “time and industrial capacity”—not just capital investment—to deploy new technology.

[Nakicenovic \(1986\)](#) discusses the logistic form of the diffusion of technology in a variety of fields and identifies several examples of diffusion of automotive features. Nakicenovic also discusses differences among different types of vehicle features, a concept continued here with the differentiation among safety, powertrain, and comfort/convenience features. Nakicenovic cites examples of the time to reach 50% penetration of a new technology, a parameter referred to later in this chapter as “developmental lag time.”

This paper updates the work performed by Nakicenovic with nearly 25 years of new data on a broader array of technologies. The larger quantity of data available also allows secondary regressions of fit characteristics.

Important Characteristics and Secondary Regression

In the form used here logistic regressions incorporate three primary characteristics: maximum take rate (or application), maximum growth rate (slope of the curve at its inflection point) and lag time, or delay in reaching the period of maximum growth as shown in [Figure 1](#).

Several examples of actual take rates and least-squares regression fits with a logistic form are shown below:

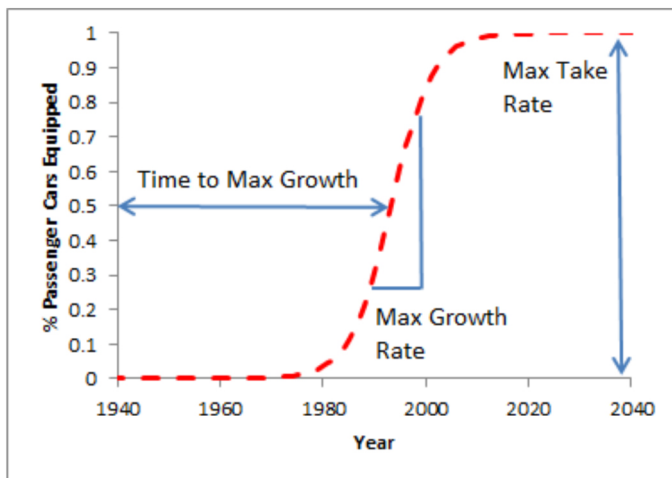


Figure 1. Important characteristics of logistic regression.

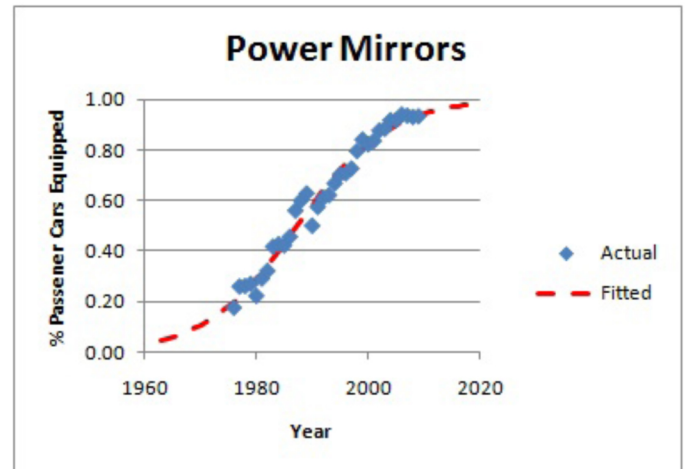


Figure 2. Actual take rate and regression fit for power mirrors.

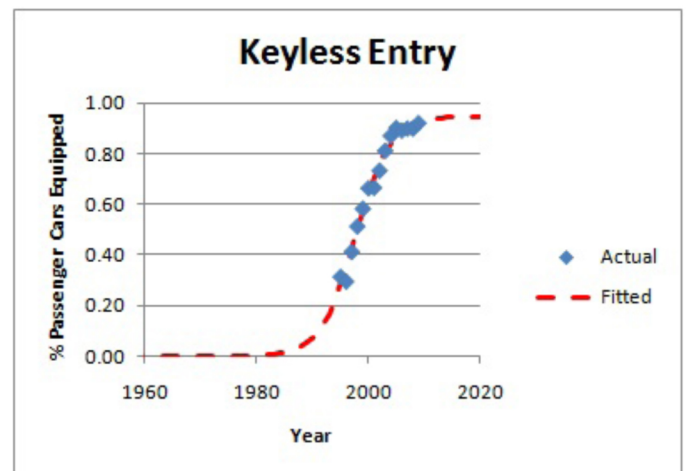


Figure 3. Actual take rate and regression fit for keyless entry.

A complete list of features that have been analyzed in this work is available in [Appendix B](#), and a more thorough discussion can be found in Stephen Zoepf's thesis ([Zoepf, 2011](#)).

Maximum take rate

Unlike stand-alone products where a potential market needs to be identified, the sales of a particular feature of a passenger car cannot exceed sales of the car itself. As a result, the potential market is defined as the percentage of the new car fleet equipped with a given feature.

When examining historical maximum take rates, one soon encounters a problem: for most features where data is available, take rates have either already approached 100% or are projected to reach this saturation point. The reason for this is simple: data is not closely tracked for technologies that

are unsuccessful! At first blush this would seem to lead to a problem of selection bias, but a closer look is appropriate.

Examples of actual failed attempts to bring features to market in the automotive industry are not found in this data set. When take rates for a given feature do fall it is generally the result of a technology supersession: eight-track players are replaced by cassette decks and CD players; traction control is replaced by stability control.

The question, then, seems to be one of boundary definition. Broadly defined, fuel injection has now saturated 100% of the new passenger car market. However, the growth in the use of fuel injection was in fact characterized by the successive uptake of mechanical fuel injection, throttle-body fuel injection, and port fuel injection as shown in Figure 2. Since the development of this figure Gasoline Direct Injection (GDI) has seen large gains in use and may soon surpass other existing types of fuel injection.

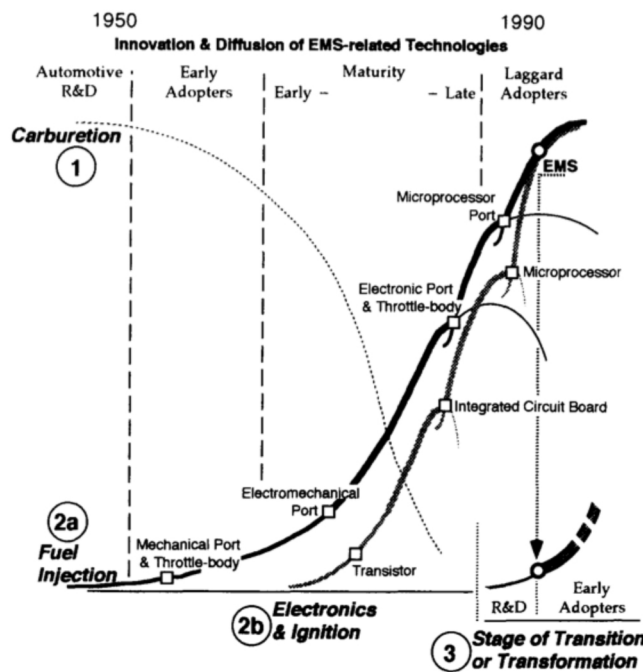


Figure 4. Technology supersession in fuel injection and engine management as envisioned by Amey.

Technology supersession is not always entirely contained within the automotive domain. Two recent examples-mobile phones and navigation systems-also show evidence of technology supersession. In-car phones originally reached a high of 9% of new passenger cars sold in 2000, but in the past decade the paradigm of in-car electronics has been replaced by a model in which owners are presumed to buy a separate device. Take rates of in-car navigation systems are still increasing, but an increasing number of buyers use a stand alone portable navigation system or cell phone-based navigation application. Time will tell whether a market will continue to exist for factory-installed navigation systems with large screens and vehicle integration.

With this concept in mind, three common factors arise as indicators that a technology will not reach 100% take rate:

Limited Appeal (Example: Rear seat entertainment) Some features simply will not appeal to all buyers. Rear Seat DVD players, for example, are generally considered desirable by buyers with small children but are of very limited use to a large fraction of buyers.

Significant Tradeoffs (Examples: Automatic Transmission, Front-Wheel Drive) Some features or technologies inherently involve tradeoffs in other attributes. Automatic transmissions, for example, remove the feel of control that some buyers want. Front-wheel drive, while offering a benefit to fuel economy, requires the sacrifice of rear-wheel drive handling dynamics sought after by some buyers.

Competing Technology / Paradigm (Example: On-board Navigation) Some features and technologies compete with others for market share. On board navigation, for example, competes with mobile phones and portable navigation devices.

Maximum growth rate

The maximum rate at which the take rate of a technology grows is dependent on a variety of factors: consumer demand, producers' ability to bring the technology to market on its fleet and, in some cases, the influence of regulation.

DeCicco (2010), while using slightly different regressions than those in this analysis, points to the maximum growth rate (UMax) of 17%/year for fuel injection in LDVs, 11%/year for front wheel drive in passenger cars. While DeCicco does not perform an explicit regression on other technologies, the proposed value of 7.6%/year a plausible adoption rate of HEVs is similar to those he shows for multivalve engines and VVT.

However each of these technologies has, to a varying extent, been driven by regulation. Figure 5 examines a histogram of the maximum growth rate of all features for which data is available. Figure 6 performs the same analysis but divides technologies into the functional categories of safety, powertrain, and comfort/convenience.

Annual growth rates for comfort and convenience features ranged from 0.8% to 11.6% (Mean 3.6%). Powertrain features were generally adopted faster, with maximum growth rates from 2.4% - 13.4% (Mean 7.1%). Safety features saw maximum growth rates from 4.0% - 23.9% (Mean 13.6%). Thus on average safety feature growth rates are approximately double those of powertrain features, which are in turn approximately double those of comfort and convenience features.

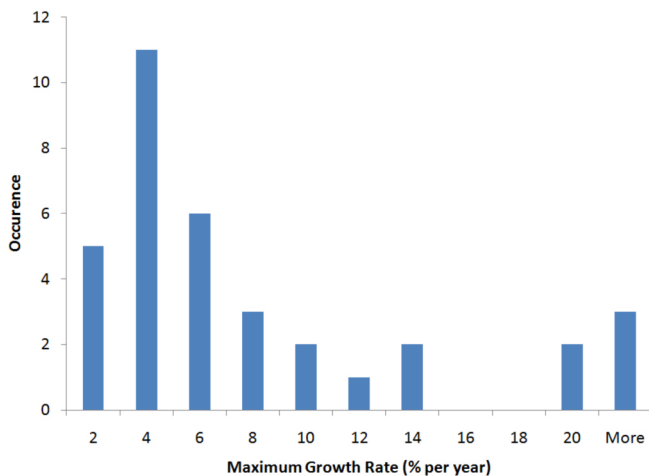


Figure 5. Histogram of maximum feature growth rates.

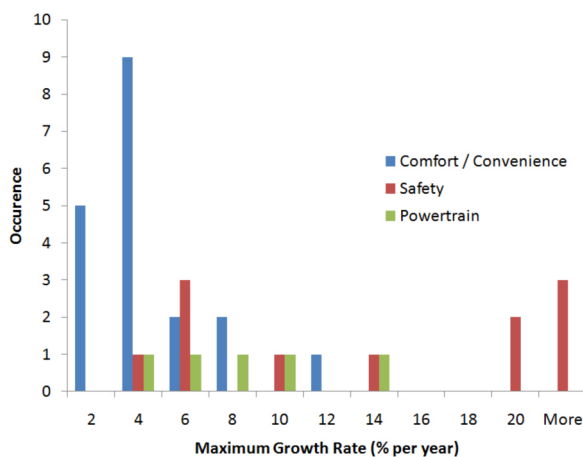


Figure 6. Histogram of maximum feature growth rate by category.

These maximum growth rates seems to confirm conventional wisdom, adopted in NHTSA (2011) and others, that an average five-year product development cycle is appropriate for modeling the automotive industry- even technologies with a clear life-saving benefit cannot be deployed much faster than 20% of the new vehicle fleet per year.

The fastest growing of the comfort/convenience features, Satellite Radio, merits additional consideration. At 11% per year, Satellite radio is currently exhibiting very rapid growth in application for a feature where regulatory impact is not a consideration. Satellite radio has been the subject of an aggressive marketing campaign in recent years. Since satellite radio is a subscription-based service it represents a stream of residual revenue from the vehicle purchaser, typical shared between the satellite radio provider and vehicle manufacturer. As a result, OEMs have an incentive to push satellite radio to

customers in the hopes that many of them will continue to subscribe. However, since the Wards data used in these regressions shows only the purchase of an option it is unknown how many of these customers actually activate the satellite radio service or are even aware of its installation.¹

Developmental lag time

When a new technology or feature is brought to market in the automotive industry it is typically done in limited quantities and often on high-end flagship products. Mercedes, for example, first brought fuel injection to market in 1954-55 on its 300SL race homologation vehicle. It was not until 1985, three decades later, that maximum growth in the mainstream automotive market was achieved. This period of development and maturation seems to be not only the product of limited consumer demand, but also of an automotive manufacturing infrastructure building competence and confidence in a new concept.

The analysis shown here is a secondary regression comparing the inflection point from primary regressions to the date of the first production, street-going vehicle to use a technology. Since many features referenced here were developed before the earliest Wards data sets used, start dates have been identified using a variety of sources including Wikipedia, patent databases, and company advertising. As such, small discrepancies may exist in some start dates. A complete table of the values used for the charts shown below is available in [Appendix B](#).

Figure 7 shows a regression of all features simultaneously, while Figure 8 shows independent secondary regressions by feature category. This analysis shows an exponential decline in the developmental lag time of features deployed over the past century.

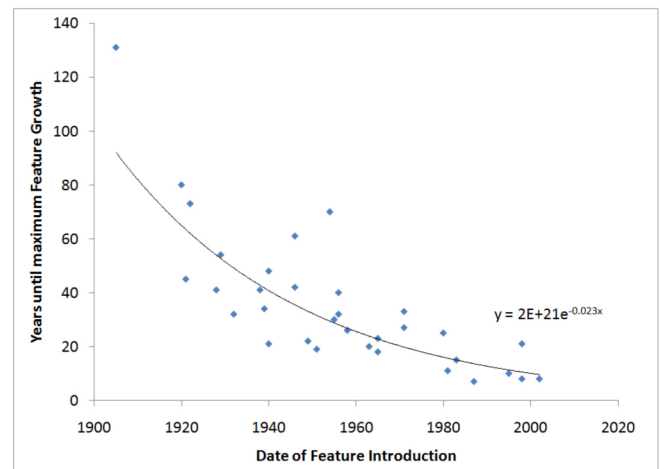


Figure 7. Historical phase-in time of all features.

¹Dealers may also receive a bonus for successfully selling options such as satellite radio. This compensation structure results in a push from every stakeholder to install satellite radio in a vehicle.