A Study of Diesel Vehicle Diffusion in Europe: Calibration and Analysis of a Consumer Acceptance and Adoption Model

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Abstract

While large scale diffusion of alternative fuel vehicles (AFVs) is widely anticipated, the mechanisms that determine their success or failure are ill understood. Analysis of an AFV transition model developed at MIT has revealed that AFV diffusion dynamics are particularly sensitive to consumers' decisions as influenced by social exposure to AFVs. While some empirical research in this area exists, uncertainty in these parameters remains high. Following principles of partial model testing in this paper we report on research that examines social exposure parameters. We focus on empirical accounts of diffusion involving diesel passenger vehicles in Europe using the historical data of diesel vehicle registrations and installed base in six European countries - France, Germany, Italy, Spain, Sweden and United Kingdom. To complete diffusion data sets we generate synthetic data. The results from the calibrations yield parameters that are in line with other marketing studies and help reduce uncertainty in the social exposure parameters. Further, the analysis suggests applicability of this model for alternative fuel vehicle markets. We discuss challenges and avenues for further research.

Keyword: Calibration, Diesel Diffusion, Adoption, Consumer Choice, System Dynamics

Introduction

Jeroen J.R. Struben and John D. Sterman (2006) developed a dynamic model of diffusion and competition among alternative fuel vehicles (AFVs), such as diesel, hybrid, compressed natural gas (CNG) and hydrogen fuel cell (HFCV). They introduced the concept of familiarity with a platform to describe a cognitive and emotional process during which drivers and non-drivers gained enough information about, understanding of, and emotional attachment to AFVs. Their analysis revealed that AFV diffusion dynamics are particularly sensitive to consumers' choices as influenced by their familiarity with different vehicle technology platforms. Familiarity is determined by customers' social exposure to different technology platforms, marketing, media attention and word-of-mouth. Struben and Sterman described social exposure parameters and showed that how these parameters influenced consumers' acceptance to AFVs and how they resulted in the existence of a critical threshold for sustained adoption of AFVs.

As a subsequent research, the study of diesel vehicle adoption in Europe serves two purposes. First is to calibrate social exposure parameters in Struben and Sterman's model using the historical data of one alternative fuel vehicle diffusion in order to reduce uncertainty in measuring social exposure parameters. Secondly, the study can test and improve the usefulness of the model by applying it to a real world vehicle technology transition example. The history of diesel adoption in Europe is a rich mine of lessons in terms of technology transition dynamics conditioned by customer acceptance and adoption, which can be applied on the transition to other alternative fuel vehicles. Diesel vehicle has enjoyed a significant market share in the passenger car market in European countries in the past few decades. Share of new diesel vehicle registrations in France and Spain has exceeded 65%. Germany and Italy have grown at an average rate of 20% since 1991 after a sales fluctuation in 1980s. However, the growth pattern of diesel share is not uniform across European countries - Sweden did not experience an obvious trend of vehicle transition from petrol to diesel, whose diesel share is only 10% in 2005. Comparisons of different adoption patterns across countries can help to understand how various factors - policy framework, customer awareness, fuel price, and infrastructure - influence diesel adoption under different circumstances.

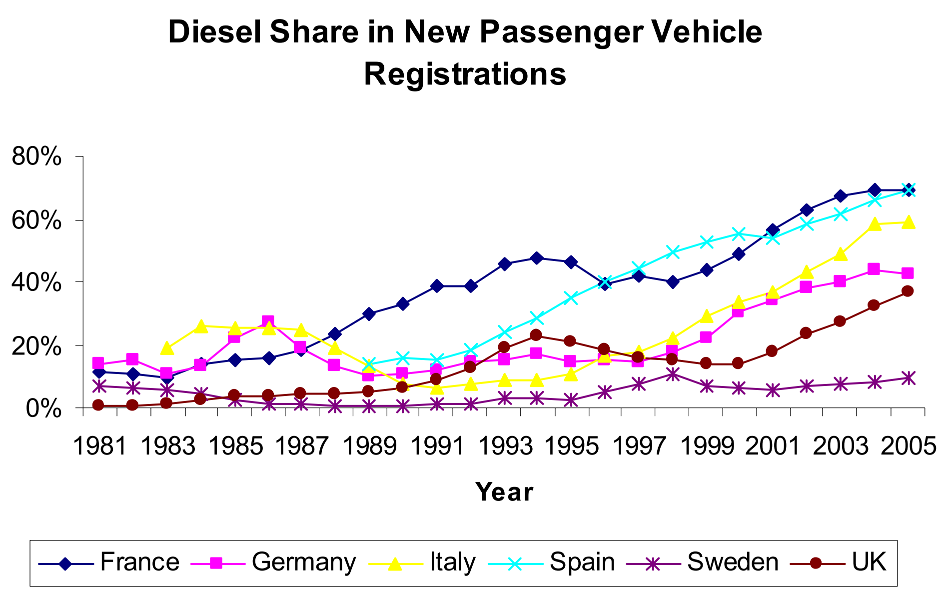


Figure 1 Diesel Share in Passenger Vehicle New Registrations

Source: R. L. Polk & Co.

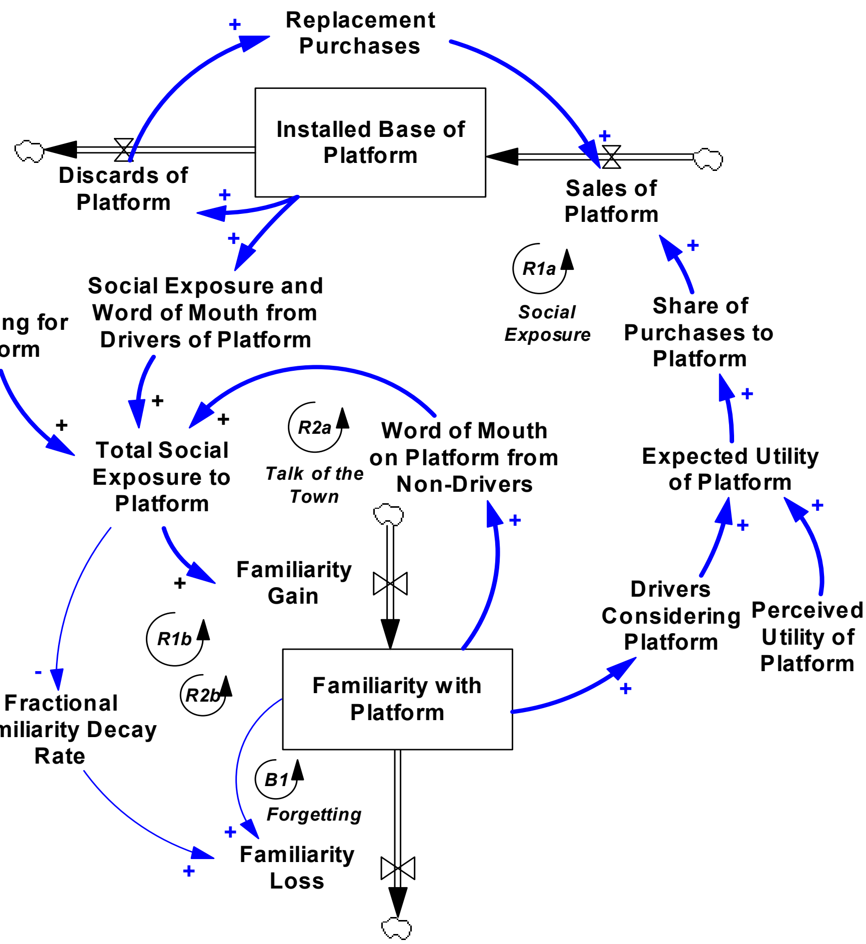


Figure 2 Principle Feedbacks in Struben and Sterman's Model

Data Completion

In order to calibrate social exposure parameters in the model, we collected vehicle registration, installed base and other related information of France, Germany, Italy, Spain, Sweden and United Kingdom from international statistical organizations (e.g. Eurostat, Euromonitor), independent vehicle industry information providers (e.g. R. L. Polk & Co., PFC Energy), and various literature sources. Periods of collected data sets vary: diesel new registrations data from 1981 to 2005; diesel installed base data from 1992 to 2004; total new registrations and installed base data from 1979 and 2004.

Based on the data, we extrapolate horizon to a year prior to the first year of new registration (1981) when the installed base diesel shares are expected to be close to zero for all six countries. Therefore the year of 1970 is considered to be a reasonable start.

In order to generate synthetic data sets from 1970 to 1980, we estimate and optimize the growth rate of new registrations before 1981 by comparing synthetic new registrations and installed base data to actual data since 1980s using a vehicle aging structure from Struben and Sterman's model (Figure 3). In this aging structure, installed base of diesel vehicles is equal to new vehicle sales less discards. Vehicle survival rate is to describe the process of vehicles to discard.

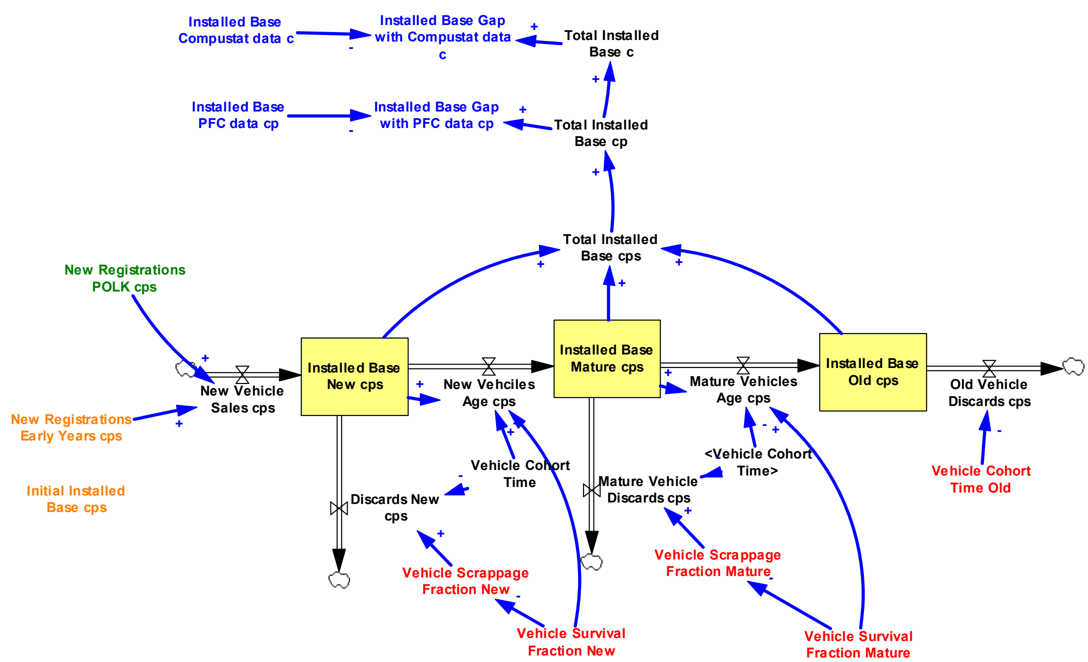


Figure 3 Vehicle Aging Structure

Abbreviation t represents time, c represents country, s represents segment, and f represents fuel platform.

The estimation approach is able to generate a smooth growth trend of early new registrations before 1981 (Figure 4). The estimated share of diesel installed base (Figure 5 and 6) also follows the historical pattern approximately. Therefore, our data generating structure proves to work appropriately.

However, confidence of estimation would be enhanced with collection of more data sets in early years, especially for countries with fluctuate levels of new registrations and installed base through years, eg. Italy.

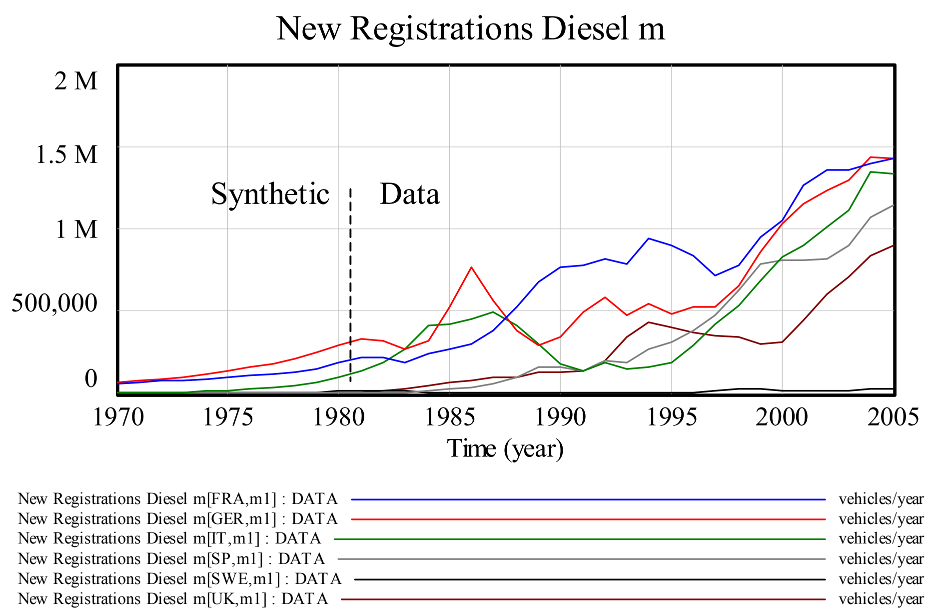


Figure 4 Diesel New Registrations (actual and synthetic)

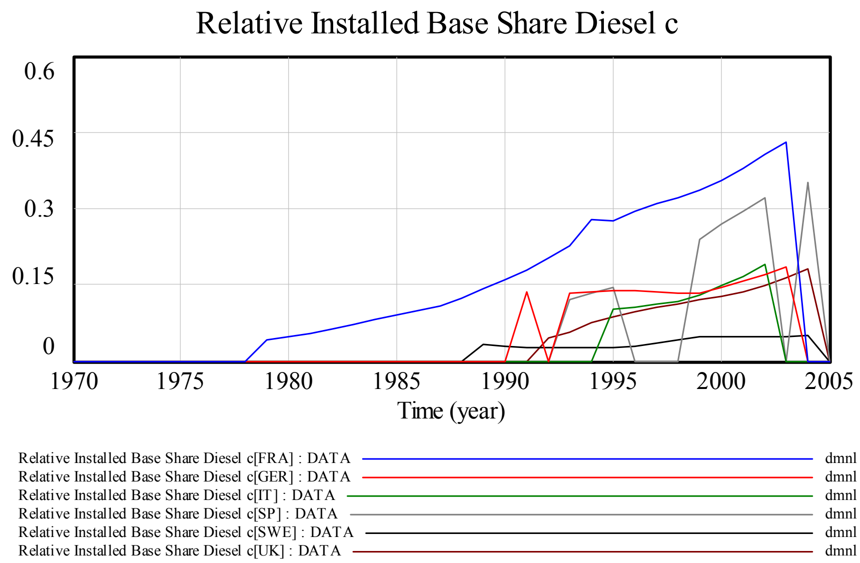


Figure 5 Installed Base Diesel Share – Actual Data Sets

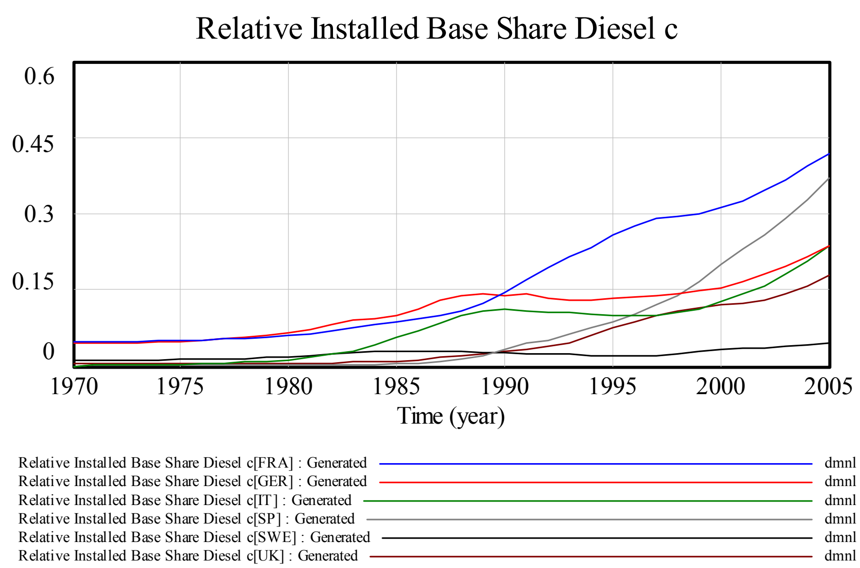


Figure 6 Installed Base Diesel Share – Synthetic Data Sets

Calibration of Social Exposure Parameters

Diesel shares, which times total sales equal to diesel sales, are estimated to be relevant to a few key factors in Struben and Sterman's model: familiarity to diesel vehicle, diesel performance, diesel vehicle price, diesel operating cost, and diesel technology availability as opposed to a petrol platform. Among these factors, familiarity to diesel vehicle is our key interest.

Sales Diesel = Share Diesel *Total Sales

Share Diesel = f (Diesel Performance, Diesel Vehicle Price,
Diesel Vehicle Taxes, Familiarity with Diesel, Diesel Effect)

Change of Familiarity with Diesel = f (Installed Base of Diesel, Familiarity of
Non-Diesel Driver with Diesel)

Familiarity with diesel parameters are the key parameters to be estimated, but given the derivation of share, we need to have a proxy for diesel utility, of which main components are diesel vehicle price, operating cost (vehicle taxes) and performance. Data are available on diesel vehicle price, diesel vehicle taxes. Others, like diesel performance, need to be approximated or included in the estimation. Diesel effect describes the impact of other factors as a whole.

Following principles of partial model testing, we import a full range of collected and synthetic data sets into Struben and Sterman's model, which has been converted for diesel vehicle study, and optimize social exposure parameters - contact effectiveness in non-drivers, contact effectiveness in drivers, market effectiveness, and initial familiarity – by calibrating model outputs to real data (Figure 7).

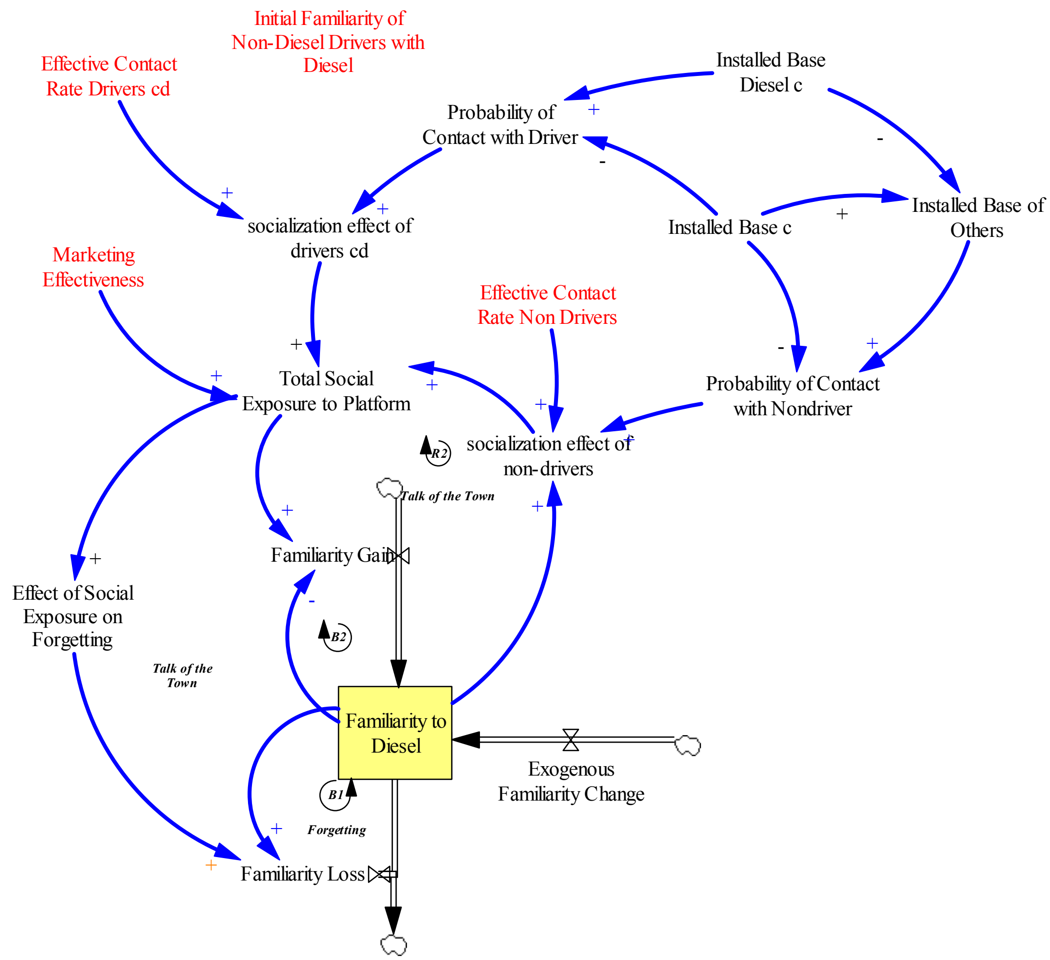


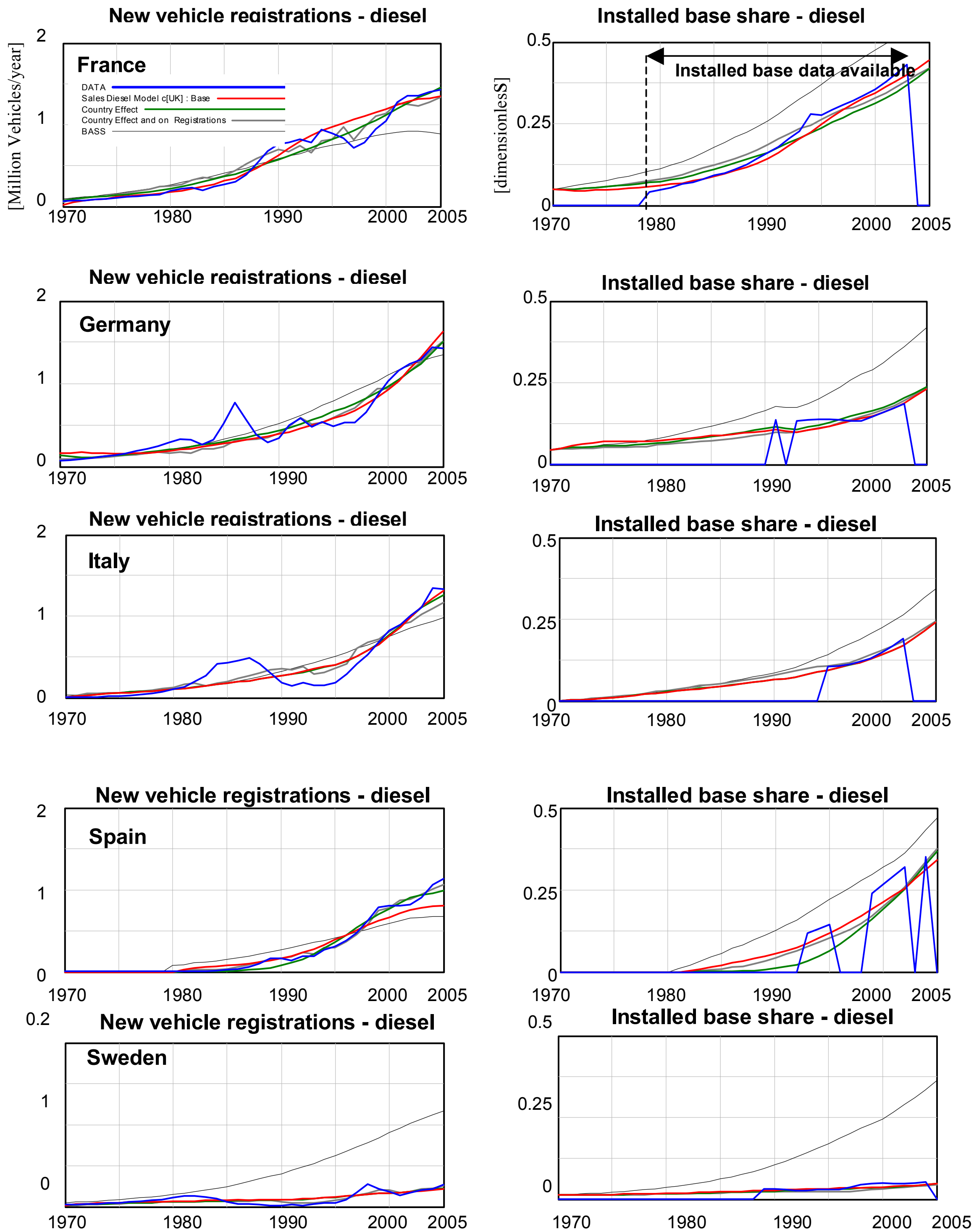
Figure 7 Social Exposure Parameters in Struben and Sterman's Model

Results

The behavior reproduction, shown in Figure 8, indicates that this model can replicate key patterns of new registrations and diesel share over time while the model of Bass (2004) has difficulty in replicating sharp inflections, e.g. Italy, and low penetration, e.g. Sweden. Statistical report of behavioral reproduction tests (Figure 9) suggest appropriate fit of the familiarity model. More country specific data will improve this considerably as country specific models (DEC) perform much better statistically.

Social exposure parameters ranges have been considerably constrained compared to earlier knowledge. The calibrated social exposure parameters (Figure 10) are in line with other marketing studies while increasing their numerical accuracy. Our qualitative observations indicate that the social exposure model proves to be critical for capturing key behavior patterns of both slow and fast adoption. The analysis suggests applicability of this model for the real world alternative fuel technology transition.

Furthermore, we observe other factors, except for vehicle price, operating cost and performance, yield a positive diesel effect (Figure 11). We haven't observed the market saturation to validate this diesel effect. More data and historic analysis on vehicle attitudes and attributes across countries, eg. Spain vs Sweden, will shed light. Used car market allowing for faster adjustment to the equilibrium market share can be expected to reduce the large "new platform effect" too.


New vehicle registrations - diesel
Installed base share - diesel
France
DATA
Sales Diesel Model c[UK] : Base
Country Effect
Country Effect and on Registrations
BASS
[Million Vehicles/year]
[dimensionlessS]
Installed base data available
Germany
Italy
Spain
Sweden
1970
1980
1990
2000
2005

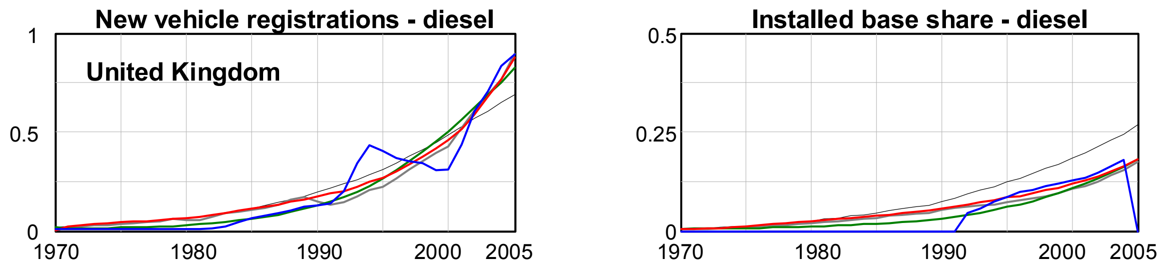


Figure 8 Behavior Reproduction

	BASS	BASE	BASE DEC	BASE NVR	BASE DEC NVR	Units
Basic Report						
Scalar Parameters	1	2	1	2	1	-
Country Specific Parameters	1	2	3	2	3	-
Number of Fitted Coefficients	7	14	19	14	19	-
Number Simulations	>50,000	>100,000	>200,000	>100,000	>200,000	
Mean Absolute Error Fraction MEA/MEAN	0.32	0.19	0.18	0.19	0.19	-
Mean Square Error (MSE)	2.18E+10	9.46E+09	8.10E+09	9.40E+09	8.20E+09	(vehicles/year)^2
Root Mean Square Error (RMSE)	1.48E+05	9.72E+04	9.00E+04	9.69E+04	9.06E+04	(vehicles/year)
Adjusted R2 **)	0.858	0.931	0.940	0.932	0.939	-
Theil Statistics						
Um - bias proportion	0.000	0.000	0.002	0.001	0.000	-
Us - variance proportion	0.198	0.013	0.014	0.013	0.033	-
Uc - covariance proportion	0.802	0.987	0.984	0.986	0.967	-
Theil - adjusted to best performance						
Um - bias proportion	0.000	0.000	0.002	0.001	0.000	-
Us - variance proportion	0.325	0.015	0.014	0.014	0.033	-
Uc - covariance proportion	0.732	0.978	0.984	0.977	0.966	-

**) Fraction of data "explained" by the model; using correlation coefficient of predicted and realized changes
Um: e.g. mean of model and data are different (systematic)
Us: e.g. data and model have different trend (typically systematic)
Uc: e.g. phase shifts and noise - typically unsystematic (depending on purpose)

Figure 9 Behavior Reproduction Statistical Test

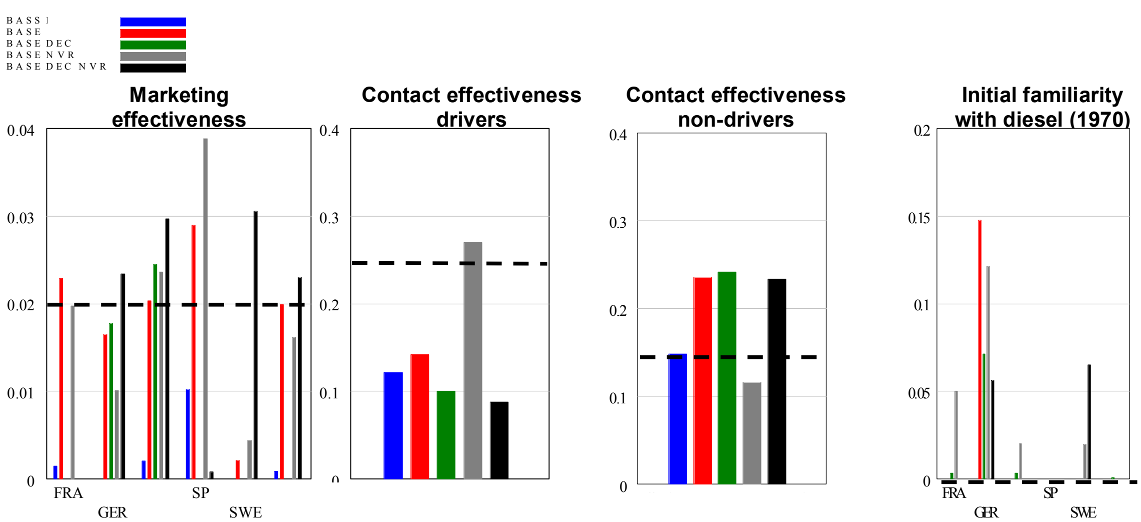


Figure 10 Social Exposure Parameters

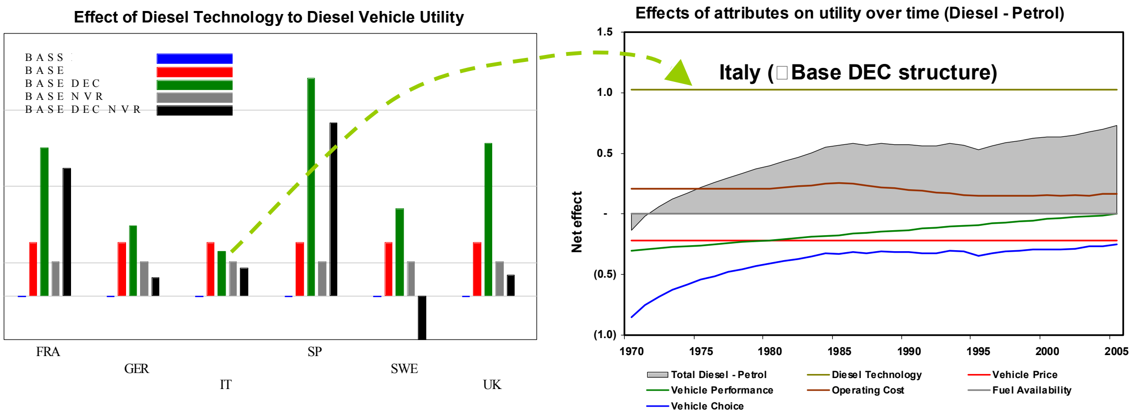


Figure 11 Diesel Effect

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