

Consumer value of fuel choice flexibility - a case study of the flex-fuel car in Sweden

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Abstract

Purpose This paper examines the value of fuel choice flexibility derived from a flex-fuel engine.

Method Based on the stochastic properties of fuel prices, we use Monte-Carlo simulation in order to value the option to switch fuel.

Results Our findings indicate a considerable value of fuel choice flexibility, ranging between 7,500 and 37,800 SEK, depending on the underlying stochastic process we assume that fuel prices follow. This can be compared to the state subsidy of 10,000 SEK provided until recently for buying a flex-fuel car.

Conclusion Compared to an environmentally friendly pure ethanol strategy, the switching strategy is considerably less costly, about 2,000–19,000 SEK depending on the assumed underlying stochastic process, a fact that is important to take into consideration with environmental policy.

Keywords Real option analysis · Flex-fuel car · Mean-reversion · Geometric Brownian motion

JEL code H23 · L92

1 Introduction

The climate debate of recent years has drawn increasing attention to environmental issues. Consumer demand has

shifted towards environmentally friendly alternatives and producers are forced by market demand and regulation to develop green commodities. Consumers are today more concerned than ever with how the products they use impact on the environment during the course of manufacture, distribution, usage and disposal. The car industry, for example, has long been the main object of debate regarding emission reduction targets because of the impact of car emissions on the environment and health. At the same time, until recently, only fossil fuels have been used for road transportation and these are exhaustible resources. There is consequently now a demand for renewable fuels with low emissions. However, the problem is not limited to the source and nature of fuel: engines must also use the fuel efficiently—that is, only a small fraction of energy should be lost during the transformation process (the conversion of the energy contained in the fuel into force on the car wheels).

The type of motor most popular at the moment as a green alternative is the so-called flex-fuel motor, which is capable of using different proportions of gasoline or ethanol, for example E85 (Ethanol 85 % plus 15 % gasoline). Cars with this adaptation are classified as green cars in Sweden and until recently entitled the owners to a public payment of 10,000 SEK (approximately 1,200 EURO). Car producers in turn demand a higher price for these cars, partly reflecting the higher cost of production and partly a result of profit-maximizing price differentiation. Sweden has become the third leading country for green cars based on ethanol after Brazil and the US. An important difference, however, is that Sweden imports most of the ethanol it uses, whereas the US and Brazil are both self-sufficient [8].

The flex-fuel car has previously been analyzed by means of option valuation in Bastian-Pinto et al. [2]. In this paper we try to establish whether the results previously found will hold even in the European car market, where Sweden is the largest market for flex-fuel cars. There are many differences between Brazil and Sweden which might

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influence the time series properties of gasoline and E85. This might in turn influence the option value derived from the flex-fuel engine.

This paper uses real option valuation based on the time series properties of fuel prices and Monte-Carlo simulation in order to examine whether there is a consumer value derived from the flexibility to choose the fuel used in a flex-fuel engine. In section 2 we present the development of the green car market in Sweden and the legal background and incentives provided by the state in order to promote green cars. Some earlier research results are also given in section 2. In section 3 we move on to the methods used in this paper. In section 4 we perform the analysis of the switching option based on the time series properties of ethanol and gasoline prices. The approach we use follows closely the analysis by Bastian-Pinto et al. [2]. Our findings indicate a considerable value of fuel choice flexibility, ranging between 7,500 and 37,800 SEK, depending on the underlying stochastic process we assume that fuel prices follow. This can be compared to the state subsidy of 10,000 SEK provided for buying a flex-fuel car and the flexi-fuel premium charged by Volvo of 6,000 SEK. The paper concludes in section 5 with a discussion of our results.

2 The flex-fuel car in Sweden

The flex-fuel car was first introduced in Sweden in 1994, when three Ford Taurus flex-fuels were imported from the US. Compared to a so-called bifuel-driven car, the flex-fuel engine allows for differing proportions of ethanol in the fuel [2]. The idea was to demonstrate that the technology existed and that it worked in practice [7]. The public responded with great interest and in February 1995 a project was initiated to import 50 flex-fuel cars, which ended up in different parts of Sweden. Only one chain of gas stations agreed to make ethanol available.

In 1998 Stockholm City, in cooperation with the Swedish FFV Buyer Consortium, offered to buy 2,000 flex-fuel cars from any car producer capable of delivering them. The purpose of this initiative was to incentivize car manufacturers to start up production of flex-fuel cars by providing a secure buyer and thereby give Sweden a first-mover advantage in the technology. However, the two Swedish car manufacturers, Saab and Volvo, declined this offer, as did other European manufacturers. The car producers gave the insufficient number of gas stations with ethanol as their reason for this, while fuel providers gave the insufficient number of flex-fuel cars as their reason for not building ethanol gas stations. It was the American division of Ford that accepted the offer, making it possible for Sweden to import the flex-fuel version of Ford Focus [8]. Hence, Ford became the first company offering a flex-fuel car to Swedish consumers.

The first car was delivered to a customer in 2001 and in 2005 more than 15,000 Ford Focus with flex-fuel engine were sold in Sweden, a market share of 80 % of flex-fuel cars. During 2005 the Swedish manufacturers Volvo and Saab introduced their flex-fuel models. Figure 1 shows the exponential growth in sales of flex-fuel cars 2001–2008 and the subsequent decline. Sweden is still the country in Europe with the most flex-fuel cars.

The number of gas stations providing ethanol has increased in a similar way since the introduction of the first station providing ethanol in 1995, with the number reaching 1,400 in 2009 (SEKAB 2009). The ratio of ethanol gas station to flex-fuel cars is very high in comparison with the US, where six million flex-fuel cars share about 1,500 ethanol gas stations.

Politics and legal regulation have had a major impact on the introduction of the flex-fuel car and are still critical to the future of the green car industry. The Kyoto Protocol commits the EU to following certain emission targets for CO₂, one of these being the reduction of emission levels by 20 % in 2020 compared to levels in 1990. Another target, issued by the EU, is that 5.75 % of all vehicles should use renewable fuels by 2010. In 2006 a Swedish government commission proposed that by 2020 the consumption of oil in road transportation should be reduced by 40–50 % through the use of more effective motors and the development of new fuels [8].

In order to meet these targets, the following incentives for consumers have been implemented in Sweden:

- A state subsidy of 10,000 SEK when buying a new green car
- A tax reduction until 2012 for bio fuels resulting in about 30 % lower prices for bio fuels
- A 20 % tax reduction for car manufacturers producing flex-fuel cars receive
- Lower insurance costs for flex-fuel cars
- No road toll in Stockholm until 1 January 2009
- Free parking in 24 out of 25 of Sweden's largest cities

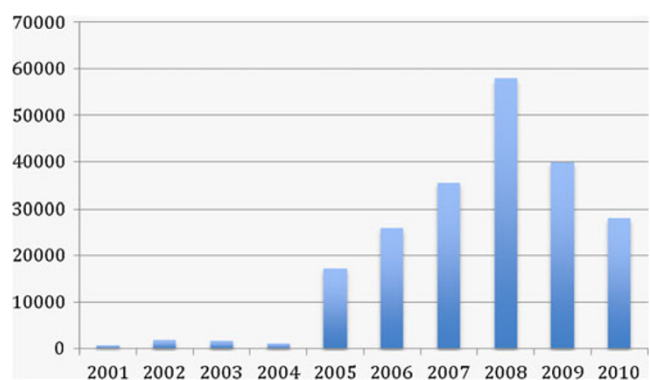


Fig. 1 The number of flex-fuel cars sold in Sweden (Source: Bio Alcohol Fuel Foundation)

It is probable that these incentives are part of the explanation for the rapid increase in green car sales in Sweden. This increase has also increased demand for bio fuels. Sweden is dependent on imports of these bio fuels because it is not cost-effective to produce the amount required to meet demand in Sweden. About 80 % of ethanol supply in Sweden is imported, mostly from Brazil [9]. Hence, ethanol prices in Sweden are affected by import tolls on ethanol. On April 3, 2009, the EU agreed to Sweden's application for lower tolls on ethanol imports from Brazil. Ethanol is produced in Europe but at a higher cost than the imported ethanol from Brazil. A low ethanol price is probably critical to keeping consumers from using fossil fuel alternatives.

3 The option to switch fuel

A financial call option is defined as the right but not the obligation to buy a certain asset at a certain time for a predetermined price. The real-option approach views an investment opportunity in real capital as an option: the right but not the obligation to invest a certain amount and thereby claim the future cash flows from the investment. One real option is the timing decision: we can, but we do not have to, invest immediately. The possibility of delaying the investment is a real option and the associated flexibility has a positive value if uncertainty exists about future cash flows. The possibility of switching (for example, switching from one input to another) is another real option. Hence, owners of flex-fuel cars have a switching option, since the fuel can be changed if altered market conditions make gasoline more economic for car drivers than ethanol and vice versa. The switching option in fact makes the flex-fuel car more valuable to consumers than either a pure gasoline car or an ethanol car.

Real options value is affected by a number of different factors, the most important of which is the uncertainty with regard to the future. The higher the uncertainty, the higher the option value becomes. The effect of the discount rate is less clear. All things being equal, the option value will be less for a higher discount rate since the future becomes less important. However, we would also expect the future growth

rate of value derived from the project to increase, so the net effect is uncertain. However, for financial call options the second effect dominates, so that the option value increases with the discount rate. The effect of risk aversion is similarly ambiguous. Table 1 summarizes and compares the key value drivers for the switching option and financial options.

4 Valuation of fuel choice flexibility

4.1 Model assumptions and data

In this section we analyze the consumer value of flexibility derived from the flex-fuel engine. As stated above, the consumer has a switching option, dependent on whether the ethanol price is higher or lower than the gasoline price.

First we have to look at the investment cost for the flex-fuel car. The cost is the difference between the price of a flex-fuel car compared to an ordinary car, hence the premium paid for the flex-fuel engine. We choose to base our analysis on the Volvo V70. Table 2 shows the relevant alternatives for our analysis. As Table 2 shows, the premium paid for the flex-fuel engine is 6,000 SEK.

Next, we look at price uncertainty with regard to ethanol (E85) and gasoline prices. We have to consider the following factors here:

- Ethanol has a lower energy content per litre than gasoline
- In Sweden, summertime E85 is used, whereas E75 is used during winter

Hence, the raw price of ethanol has to be adjusted for both these factors in order to compare ethanol and gasoline. We use monthly consumer price deflated data for gasoline and ethanol for the period 2005–2010 obtained from SPBI (Svenska Petroleum & Biodrivmedel Institutet). Figure 2 shows the price series.

Figure 2 shows that, on average, E85 is cheaper than gasoline; however, for two periods the reverse is true. Moreover, we can see that gasoline has had a more volatile development than E85 and that E85 experienced a slight trend

Table 1 Key value drivers for the option to switch fuel

Financial options	Switching option	Impact on option value
Volatility of stock price	Volatility of future fuel prices	+
Exercise price	Premium paid for flex-fuel engine	–
Time to expiration	Window of opportunity for investment (for example, subsidy for purchase)	+
Risk-free interest rate	Risk adjusted interest rate/risk-free interest rate	(+)
Dividend	Value lost during option lifespan (for example, changes in taxes and subsidies affecting fuel prices)	–
Stock price	Expected discounted cost-savings from switching	+

Table 2 Volvo price list April 20, 2009

Model	Price	Engine	Price premium
V70	267 900 SEK	2.0 F flex-fuel 145hk	267 900–261 900=6 000 SEK
V70	261 900 SEK	2.0 Bensin 145hk	

upward. In Table 3, estimates for growth rates and volatility are shown.

In our analysis we consider the flexibility the consumer has with regard to choice of fuel. Considering the lower energy content of ethanol, the rational consumer would not use E85 as long as the price of E85 is higher than 70 % of gasoline price.

In order to determine the value of the switching option we assume that each car is refuelled twice a month during a period of 10 years (120 months). As mentioned above, we look at the Volvo V70 2.0 F with flex-fuel engine; this model has a 70-l tank capacity, so its monthly fuel consumption is 140 l gasoline, corresponding to 200 l of E85.

We have also to consider the stochastic properties of E85 and gasoline. At the beginning of the period we assume that the price for gasoline is 12 SEK and for E85 8.40 SEK. This implies that the consumer is initially indifferent between the two fuels. The initial costs for gasoline and ethanol are:

- Costs for E85 = $2/0.7 \cdot 70 \cdot 8.4 = 1,680$ SEK
- Costs for gasoline = $2 \cdot 70 \cdot 11.50 = 1,680$ SEK

At time of refuelling the consumer uses the fuel that is more cost-effective. We use the Monte Carlo method to solve this real option problem, consisting of a series of independent European options. At each time the choice of fuel is independent of the choices in all other months before or after. Initially, we look at the costs for gasoline and E85 at each time t . The costs are hence as follows:

$$C_E = E_t \cdot 2 \cdot 70 \cdot \frac{1}{0.7} = 200E_t \quad (1)$$

$$C_G = G_t \cdot 2 \cdot 70 \cdot \frac{1}{0.7} = 140G_t \quad (2)$$

Table 3 Growth rates and volatility

	Gas	E85
Monthly		
Mean growth rate	0.24 %	0.14 %
Std dev (σ)	3.54 %	2.58 %
Correlation (ρ)	0.030	
Annual		
Mean growth rate	2.93 %	1.66 %
Std dev (σ)	12.26 %	8.94 %
Correlation (ρ)	0.043	

Next we determine the costs, given that each month only the most cost-effective fuel is chosen. The cash flows have to be discounted by the risk-adjusted interest rate. Since ethanol and gasoline are both traded in financial markets, the risk inherent in the real option to switch fuel can be eliminated by holding a portfolio of assets offsetting the payoffs from the option. Hence, the appropriate risk adjusted discount rate is the risk-free interest rate.

$$NPV_{Cost} = \sum_{i=1}^{120} \frac{\min(C_{E_t}, C_{G_t})}{(1+r)^i} \quad (3)$$

4.2 The stochastic process followed by gasoline and ethanol

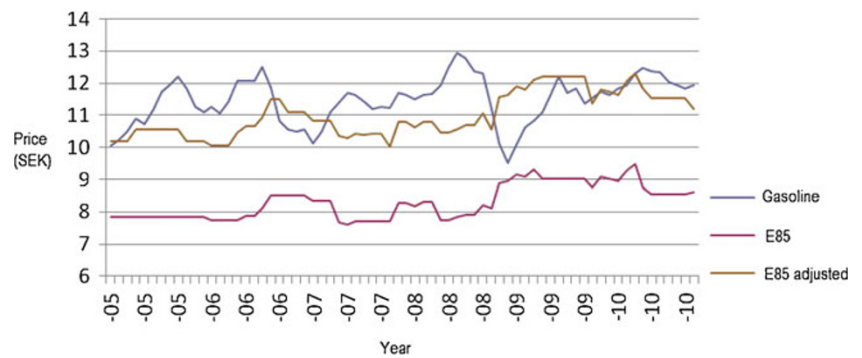
In order to use Monte Carlo simulation we have to know the underlying stochastic process for gasoline and ethanol. Basically, we have to discern between a mean-reverting process (MRP) and random-walk with trend (also known as geometric Brownian motion, or GBM). This implies that we have to test for a unit root in the price series. In order to do so we perform OLS-estimation of the following equation:

$$\ln(p_t) - \ln(p_{t-1}) = a + (b-1)\ln(p_t) + \varepsilon_t \quad (4)$$

The t-value for the price coefficient (an estimate for $b-1$) is compared to the critical values from the Dickey-Fuller table. The null hypothesis is that the coefficient is zero, that is, that the price series follow a random walk with trend. If we reject the hypothesis and b is in the interval $0 < b < 1$ it means that we have an autoregressive process, which tends to revert to its long-run mean value, and is therefore equivalent to a mean reverting model in continuous time. The regression results are found in Table 4.

The critical t-value for a significance level of 95 % is -2.93 and is taken from the Dickey-Fuller table since it follows a tau-distribution. The t-values for the slope coefficients are lower than the critical value and this implies that we cannot reject the null hypothesis of a unit root. However, we have to be careful in concluding that we have a random walk; it could well be the case that we only have insufficient data to reject the null hypothesis. Moreover, theoretical considerations suggest that the price series should exhibit mean reverting behaviour. For gasoline the test statistic is close to the critical value for the 95 %-confidence level and is rejected at the 90 %-confidence level. As Pindyck [4] shows for very long time series of energy prices, not rejecting the presence of a unit root does not necessarily

Fig. 2 Price series of ethanol (E85) and gasoline



imply that the price process has to be modelled as GBM. A slowly reverting MRP with a shifting trend makes it difficult to distinguish between a random walk and a mean reverting process. Hence, in the following section we will examine both GBM and MRP.

4.3 Simulation with GBM

If we model the processes as a GBM we have the following price processes for gasoline and ethanol:

$$dX_t = \mu X_t dt + \sigma X_t dB_t \tag{5}$$

where dX is the price increment in a infinite short time interval dt , μ is the mean drift, σ is the volatility and $dB_t = \varepsilon\sqrt{dt}$ is the so-called Wiener process or Brownian motion with ε following a standard normal distribution. The Wiener increments can be correlated between different stochastic processes. Equation (5) is a differential equation with the analytical solution derived with Ito’s lemma:

$$X_t = X_0 e^{(\mu - 0.5\sigma^2)t + \sigma B_t} \tag{6}$$

where B_t is the sum over dB_t up to t . We simulate the time paths using a discrete time increment Δt with a length of 1 month, equivalent to 1/12 year. In order to estimate the parameter values for the GBM we have to express Eq. (5) in discrete time. Based on Eq. (6):

$$X_t = X_{t-1} e^{(\mu - 0.5\sigma^2)\Delta t + \sigma\varepsilon\sqrt{\Delta t}} \tag{7}$$

Table 4 Regression results

	Gasoline	E85
a	0.4350	0.2212
b-1	-0.1776	-0.0915
b	0.8224	0.9084
t-value for b-1	-2.7784	-1.8494

$$\ln\left(\frac{X_t}{X_{t-1}}\right) = \mu - 0.5\sigma^2 \Delta t + \sigma\varepsilon\sqrt{\Delta t} \tag{8}$$

If we set time $\Delta t=1$:

$$\ln\left(\frac{X_t}{X_{t-1}}\right) = \ln(X_t) - \ln(X_{t-1}) = \mu - 0.5\sigma^2 + \sigma\varepsilon \tag{9}$$

Taking expectations, we can from the first difference of log prices calculate the drift rate as $\mu = E[\ln(X_t) - \ln(X_{t-1})] + 0.5\sigma^2$ and the standard deviation σ . Figure 3 shows for illustration purposes five simulated time paths each for gasoline and ethanol. The prices deviate considerably from their start values due to the deterministic time trend and the stochastic time trend from the Wiener process, resulting in large price difference between the fuels.

In Table 5 the results from 1,000 simulations for a 120-month period can be found. We assume that the price series of gasoline and ethanol are uncorrelated with the overall market portfolio of all assets, meaning that the drift does not need to be adjusted by the market price of risk and hence that the risk-free interest rate is appropriate to use. We assume a real risk-free interest rate of 2 % on average for the option lifetime.

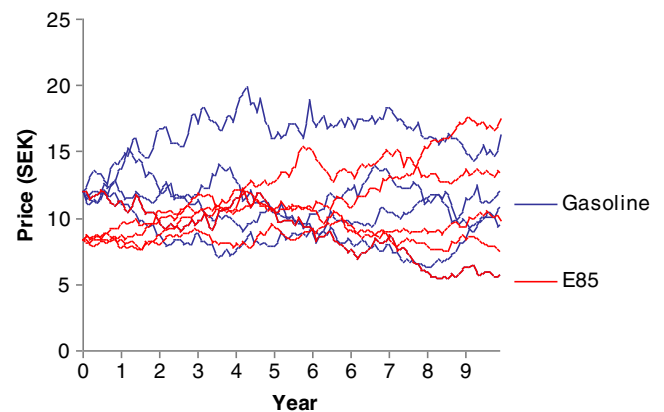


Fig. 3 Simulation of GBM 10 years ahead

Table 5 Option value for GBM

	Results
Discounted costs for gasoline	221 479 SEK
Discounted costs for ethanol	202 765 SEK
Discounted costs for min[gasoline, ethanol]	183 625 SEK
Value of Switching option	37 854 SEK
Option value – option price (flex-fuel premium)	= 37 854–6 000=31 854 SEK
Net value+plus subsidy	= 31 854+10 000=41 854 SEK

4.4 Simulation with MRP

Usually, commodity prices are modelled as a mean reverting process, since the prices tend to revert to their long run marginal costs of production. The simplest model for a MRP is:

$$dY_t = \eta(\bar{Y}-Y_t)dt + \sigma dB_t \tag{10}$$

where Y_t is the natural logarithm of the price in order to avoid negative prices, η measures the speed of reversal as price deviates from the mean value, σ is the volatility of the process and dB_t is the increment of a Wiener process. For simulation purposes, the price evolution has to be expressed in discrete time intervals:

$$Y_t - Y_{t-1} = (e^{-\eta\Delta t} - 1)(Y_{t-1} - \bar{Y}) + \varepsilon = \bar{Y}(1 - e^{-\eta\Delta t}) + Y_{t-1}(e^{-\eta\Delta t} - 1) + \varepsilon \tag{11}$$

The analytical solution for the discrete time version is [2,5]:

$$X_t = \exp\left(\ln(X_{t-1})e^{-\eta\Delta t} + \left(\ln(\bar{X}) - \frac{\sigma^2}{2\eta}\right)(1 - e^{-\eta\Delta t}) + \sigma\sqrt{\frac{1 - e^{-2\eta\Delta t}}{2\eta}}\varepsilon\right) \tag{12}$$

Rewriting Eq. 11 we can compute the parameters of the MRP model with our data (see Table 4).

$$\ln X_t - \ln X_{t-1} = \bar{Y}(1 - e^{-\eta\Delta t}) + Y_{t-1}(e^{-\eta\Delta t} - 1) + \varepsilon_t \tag{13}$$

From Ito’s lemma:

$$\bar{Y} = \bar{X} - \frac{\sigma^2}{2\eta} \tag{14}$$

Substituting:

$$\ln X_t - \ln X_{t-1} = \left(\ln \bar{X} - \frac{\sigma^2}{2\eta}\right)(1 - e^{-\eta\Delta t}) + \ln X_{t-1}(e^{-\eta\Delta t} - 1) + \varepsilon_t \tag{15}$$

By comparing Eqs. (13) and (4) we can identify the parameter values for the MRP:

$$b - 1 = e^{-\eta\Delta t} - 1 \Rightarrow \eta = -\frac{\ln b}{\Delta t} \tag{16}$$

$$a = \left(\ln \bar{X} - \frac{\sigma^2}{2\eta}\right)(1 - e^{-\eta\Delta t}) = (b + 1)\left(\ln \bar{X} - \frac{\sigma^2}{2\eta}\right) \Rightarrow \bar{X} = e^{-\frac{a}{b+1} + \frac{\sigma^2}{2\eta}} \tag{17}$$

Rearranging the formula for σ_ε in Dixit and Pindyck [3], p. 77 we can estimate σ from the regression variance σ_ε :

$$\sigma^2 = \sigma_\varepsilon^2 \cdot \frac{2\eta}{1 - e^{-2\eta\Delta t}} \tag{18}$$

Table 6 gives the parameter estimates based on Eqs. (16)–(18).

Quite surprisingly, ethanol and gasoline are in practical terms uncorrelated. An explanation for this is that the exchange rate SEK/USD affects gasoline prices directly since crude oil is quoted in terms of USD. Ethanol is imported from Brazil; hence the exchange rate SEK/BRP affects ethanol prices in SEK. Moreover, gasoline is bought using short-term contracts, whereas ethanol is bought using longer contracts and hence has a delayed response to shocks that affect both gasoline and ethanol.

Table 6 Parameter estimates for MRM

	Gas	E85
η	2.34	1.15
σ	24.33	17.98
\bar{X}	11.73	11.39
ρ_{GE}	0.03	

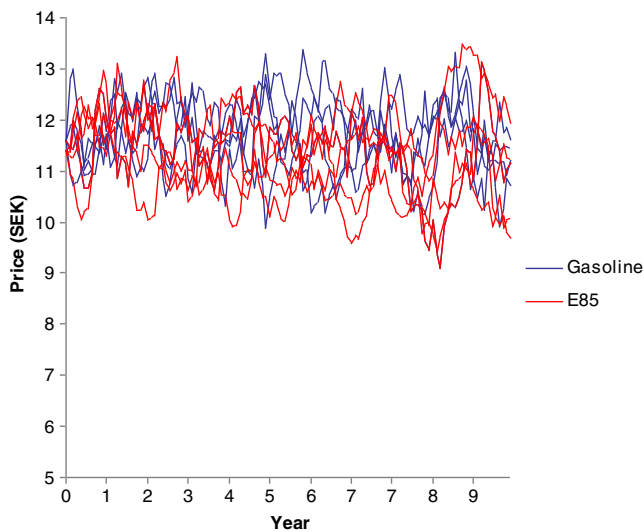


Fig. 4 Simulation of MRM 10 years ahead

In Fig. 4 we show for illustration purposes five simulated time paths each for gasoline and ethanol based on the MRM. The prices tend to fluctuate around their long-run mean value and do not have the same tendency to deviate to extremes as in the GBM.

Performing 1,000 simulations we get the results shown in Table 7. In the simulations the long-run mean is used as the starting value and since the prices are adjusted with respect to energy content it is assumed that the consumer tanks 140 l of fuel respectively each time.

4.5 Comparison GBM and MRP

In Table 8 we compare the GBM results and the MRM results. The comparison shows that, regardless of the model, the value of the switching option is positive for the consumer—that is, the value of flexibility is higher than the premium paid for the flex-fuel engine. Quite interestingly, the difference between using only gasoline or using only ethanol is small, regardless of the model we assume for price diffusion. Consequently, using the switching option, the fuel costs can be lowered considerably—about 17 % according to the GBM and about 4 % according to the MRM. Compared to an environmentally friendly pure ethanol strategy, the

Table 8 Comparison GBM vs. MRM

	GBM	MRM
Gasoline costs	221 479 SEK	178 729 SEK
E85 costs	202 765 SEK	173 385 SEK
Costs min (Gas, E85)	183 625 SEK	171 234 SEK
Value of switching option	37 854 SEK	7 495 SEK
Option value/total fuel costs	17.09 %	4.19 %

switching strategy is considerably less costly—about 2,000 SEK for MRM and 19,000 SEK for GBM—a fact that is important to take into consideration in environmental policy.

4.6 The impact of uncertainty not related to fuel prices

In the real option model presented here we only account for the uncertainty related to fuel price fluctuations. For the consumer (and hence also for the producer) there is considerably political uncertainty related to buying a green car. For example, the state subsidy of 10,000 SEK for buying a green car (ending June 30, 2009) was substituted by a tax exemption starting January 1, 2010, and ending five years later. Computations show that the savings due to the tax exemption are considerably less than the 10,000 SEK subsidy, especially since the tax savings have to be discounted [6]. Moreover, nothing is known of what will happen when the 5 years of tax exemption ends.

Another important source of uncertainty not sufficiently covered by our models of price diffusion is that the lower toll on imported ethanol is valid only 1 year ahead (and can be renewed only after a new application). Moreover, the lower price of E85 compared to gasoline is based on the tax reduction on E85, which is only valid to the end of 2012.

From both a Swedish and a European standpoint, exchange rate movements add a further uncertainty. Fuel prices are per se volatile, but exchange rates independently add volatility since they tend to “overshoot” equilibrium in the short run and often exhibit persistent deviations from long-run equilibrium.

Table 7 Option value based on MRM

	Results
Discounted costs for gasoline	178 729 SEK
Discounted costs for ethanol	173 385 SEK
Discounted costs for min[gasoline, ethanol]	171 234 SEK
Value of Switching option	7 495 SEK
Option value–option price (flex-fuel premium)	= (7 495–6000)=1 495 SEK
Net value + plus subsidy	= (1 495+10 000)=11 948 SEK

5 Conclusions

As we described earlier, a significant number of flex-fuel cars have been sold in recent years. Somewhat surprising is that although the flex-fuel model was introduced in 1994, it did not gain a major market share until 2001. One explanation for this might be the lack, initially, of a network of filling stations—something that could be described as a classic social dilemma, since the lack of ethanol stations in turn can be explained by the low number of ethanol-adapted cars. The number of filling stations has increased sharply in recent years, a prerequisite for consumers switching to ethanol-adapted cars.

Another factor contributing to the increase in demand for green cars on the Swedish market is the state incentives that have been introduced to promote more environmentally friendly car models. In this paper we are primarily interested in finding out if the switching option might be another explanation for why consumers choose to buy a flex-fuel car instead of a regular gasoline car. Despite the generally lower price at filling stations for E85 compared to gas, it can be more costly for consumers. The reason for this is that E85 has less energy content compared to gas, which means that a car requires more E85 per kilometer than gas. Hence, an adjustment has to be made to the price level to calculate the real expected fuel costs for consumers.

With this fact in mind, we want to explore whether there is any major value attributable to the option to switch fuel using a typical ethanol-adapted car for the Swedish market, the Volvo V70 2.0 F. In order to answer that question, we use methods developed for the valuation of financial options and treat the problem analogously as a real option in the form of a so-called switch option. First, we estimate parameter values and simulate monthly prices for both gasoline and E85 10-years ahead. We further assume that consumers will always fuel their cars with the cheapest alternative, hence, that they do not have any intrinsic concern for the environment.

Our results are clear-cut: we find that that the option to switch actually gives a value to the consumer which is greater than the extra investment of 6,000 SEK required for the flex-fuel engine. The value of the option varies depending on which stochastic process we assume and a higher value is found using a GBM process, where the value of the option is estimated to be about 37,800 SEK. A possible explanation for the higher estimated option value using a GBM rather MRM process, where in the latter case the estimated option value is about 7,500 SEK, is that price increases are pronounced in a GBM process, resulting in larger price deviations between the fuels (see Fig. 3). As previously mentioned, in a MRM process the stochastic process tends to vary around a long-run mean. This property prevents extreme values in our price estimations from occurring; according to Andersson [1] this model is more reasonable for estimating prices of commodities such as gas and ethanol. However, deviations can be long and persistent and the mean can shift, so that GBM could provide a better approximation than the more

complex MRM, especially considering that the data covers a relatively short time span. The option value should, in addition to previously discussed reasons, be a significant incentive for consumers to choose a car with a flex-fuel engine. It could also motivate a higher price premium for flex-fuel engines by car dealers. Compared to an environmentally friendly pure ethanol strategy, the switching strategy is considerably less costly (about 2,000–19,000 SEK depending on the assumed stochastic process), an important fact to take into consideration in environmental policy.

The results in this paper differ somewhat from those presented in Bastian-Pinto et al. [2]. They also found a higher option value with GBM than with MRM, although the total fuel cost was higher with MRM simulation. One reason for these differences is that we have a Swedish perspective and prices on fuel differ between countries for many reasons. For instance, Brazil is self-sufficient with regard to ethanol production while Sweden has to import most of their ethanol; the exchange rate will therefore be a major risk factor for market prices. Differences in policies and laws regulating the prices of fuel in each country are also a significant factor in creating price differences. To sum up, consumers who seek the most cost-effective alternative will benefit from buying a flex-fuel car. More widespread knowledge of this would probably increase the sales of flex-fuel cars.

Uncertainties that we did not consider in our model but that might be considered in future research are, chiefly: uncertainty with regard to increased import taxes, fuel taxes, removal of the green car subsidies and changes in the US dollar exchange rate. All of these uncertainties would affect the prices of the fuels and in turn the value of the option to switch fuel. Due to Sweden's commitment to an environmental friendly policy it is unlikely that any of these would be allowed to affect the price level to the extent that consumers would totally abandon the E85 and choose only gasoline in the future. Moreover, even if the value of the option would become less than the required additional investment for a flex-fuel car, it might still be a certain value of the switching option we analyze. One example is if there is a shortage of either fuel. The results presented here have, in addition to their merits for the analysis of the flex-fuel engine based on E85, wider implications regarding the potential benefits of investing in propulsion technologies which can be used with different energy sources. Since our society is full of uncertainties, consumers always yield some kind of value if they have the opportunity to change decisions as new information materializes. There are thus numerous decisions and investment opportunities, not only within transportation, that could be valued from a consumer perspective with the help of a real option approach.

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