

# Valuing plug-in hybrid electric vehicles' battery capacity using a real options framework

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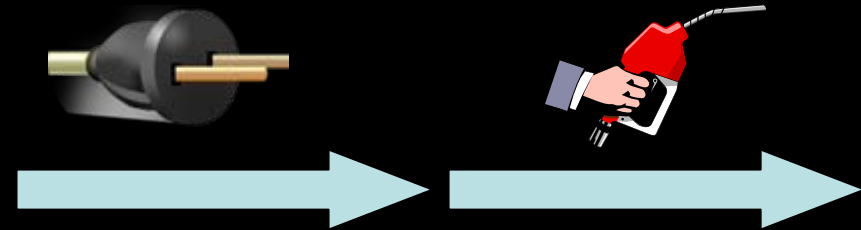
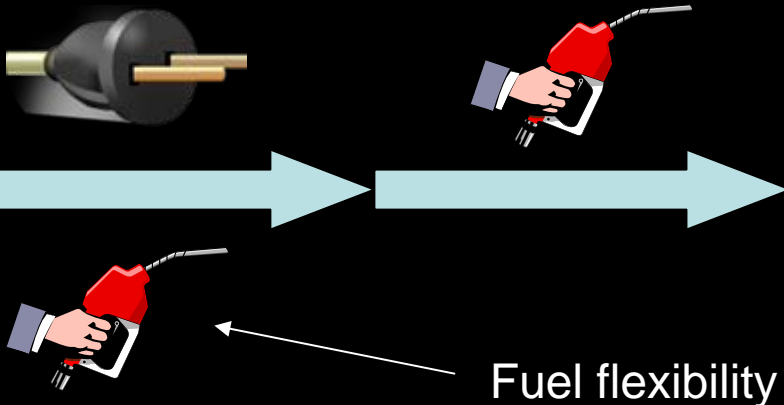
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# Real Plug-In Hybrid: Charging-Optional

# Fictional Plug-In Hybrid: Charging-Mandatory



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Previous studies of PHEV value implicitly modeled *charging-mandatory* PHEVs.

I develop and apply methods to value the fuel flexibility of the more realistic *charging-optional* PHEV.

My methods make PHEVs substantially more attractive but still probably not free.

# The Triple Benefit of PHEVs

By bringing electricity into the transportation sector, PHEVs can

- Reduce greenhouse gas emissions
- Lessen dependence on petroleum
- Improve urban air quality

# Outline

- The real options framework for dual-fuel vehicles
- Results: The value of PHEV batteries
- Implications for:
  - The cost of greenhouse gas abatement
  - PHEV business models

# The real options framework

# First, some terminology

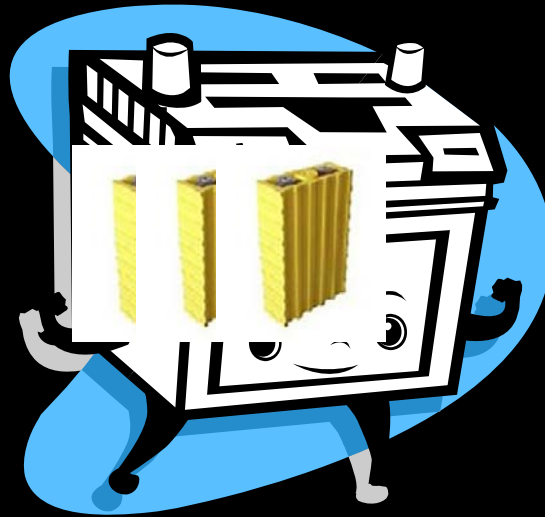
## *Real option*

The right---but not the obligation---to undertake some decision.

## *One mile of battery capacity*

The battery capacity required to provide a PHEV with one mile of charge-depleting operation (which uses grid electricity).

Battery capacity can be thought of as a bundle of miles of battery capacity.



Mile 1

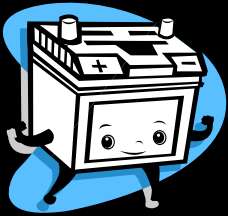
Mile 2

Mile 3

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*The value of the battery equals the total value of all the miles of battery capacity.*

Purchasing a mile of battery capacity is financially equivalent to purchasing a bundle of options.



*Therefore the value of the mile of battery capacity equals the total value of all the daily options.*

Day 1

Day 2

Day 3



OR

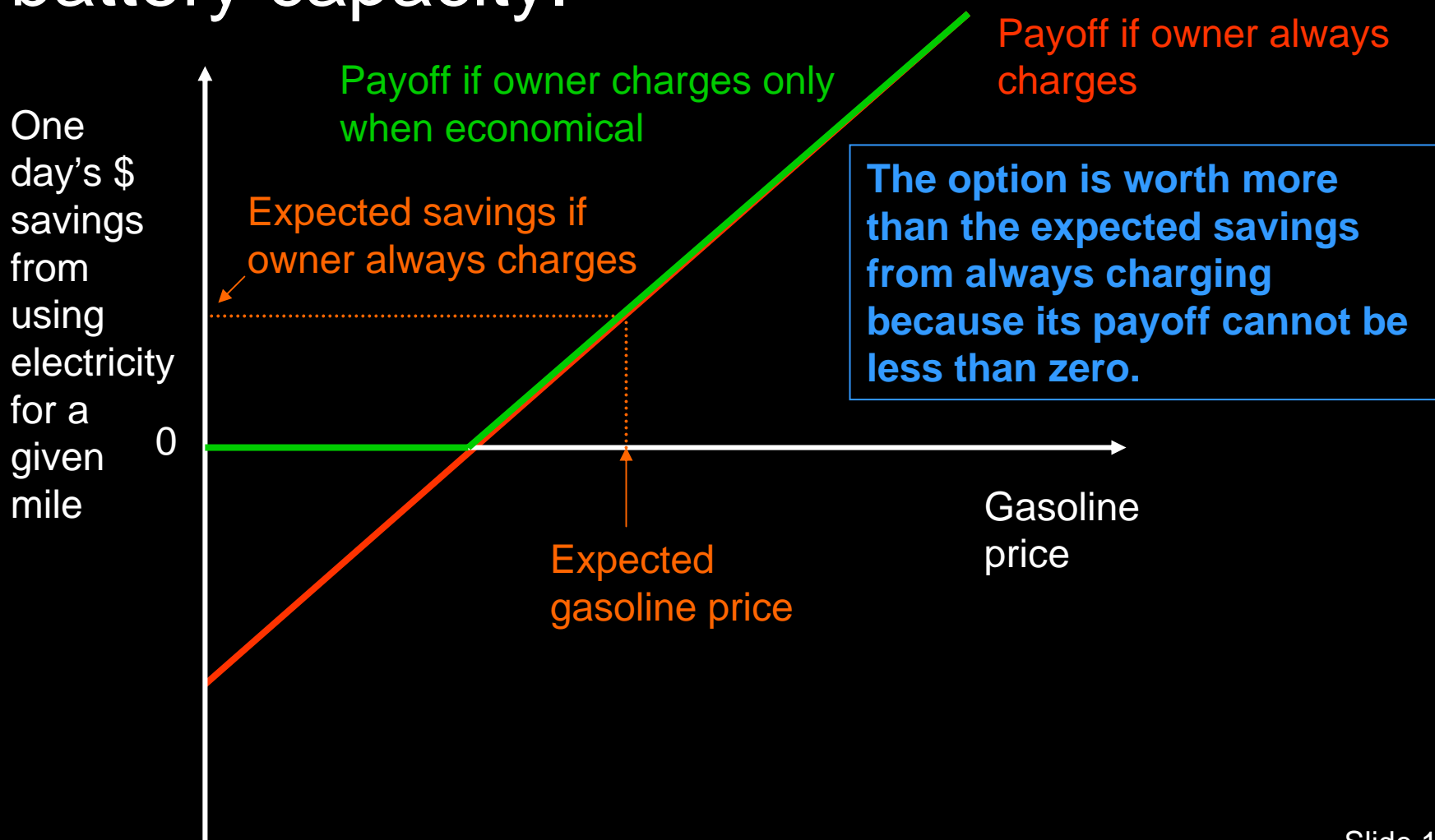
OR

OR

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# Using expected fuel prices to determine a day's fuel savings undervalues the mile of battery capacity.



# Valuing each option is mathematically complicated.

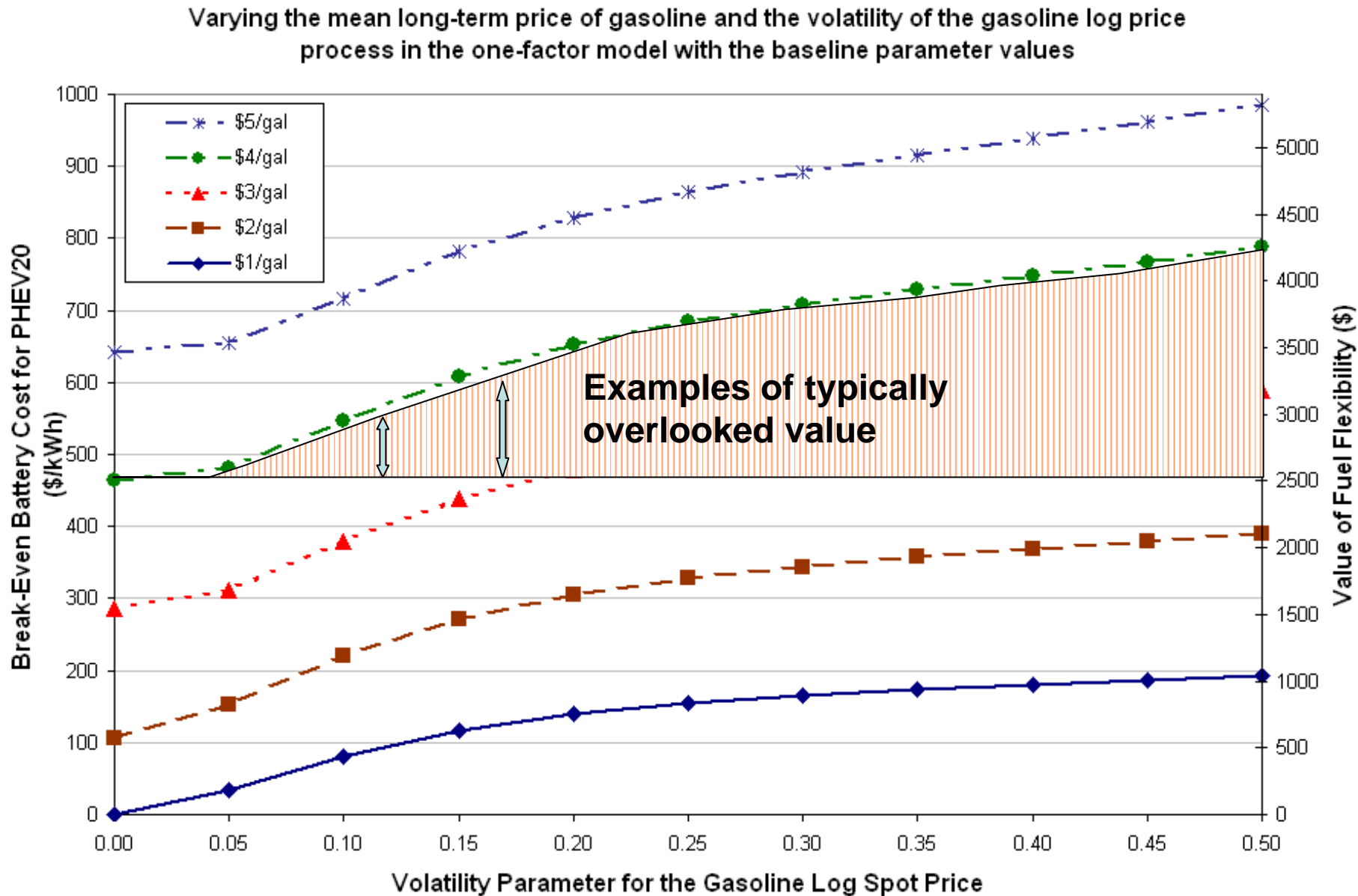
- Extending results from the asset pricing literature, I obtained closed-form solutions.
- I considered three types of gasoline price processes with deterministic retail electricity prices.
- I also solved for stochastic electricity and gasoline prices. (real-time pricing case)

# Results: The Value of PHEV Batteries

# Break-even battery cost is one indicator of the broad attractiveness of PHEVs.

- PHEVs' batteries provide fuel efficiency benefits but come at a cost.
- At the “break-even battery cost,” the additional battery capacity exactly pays for itself through fuel savings.

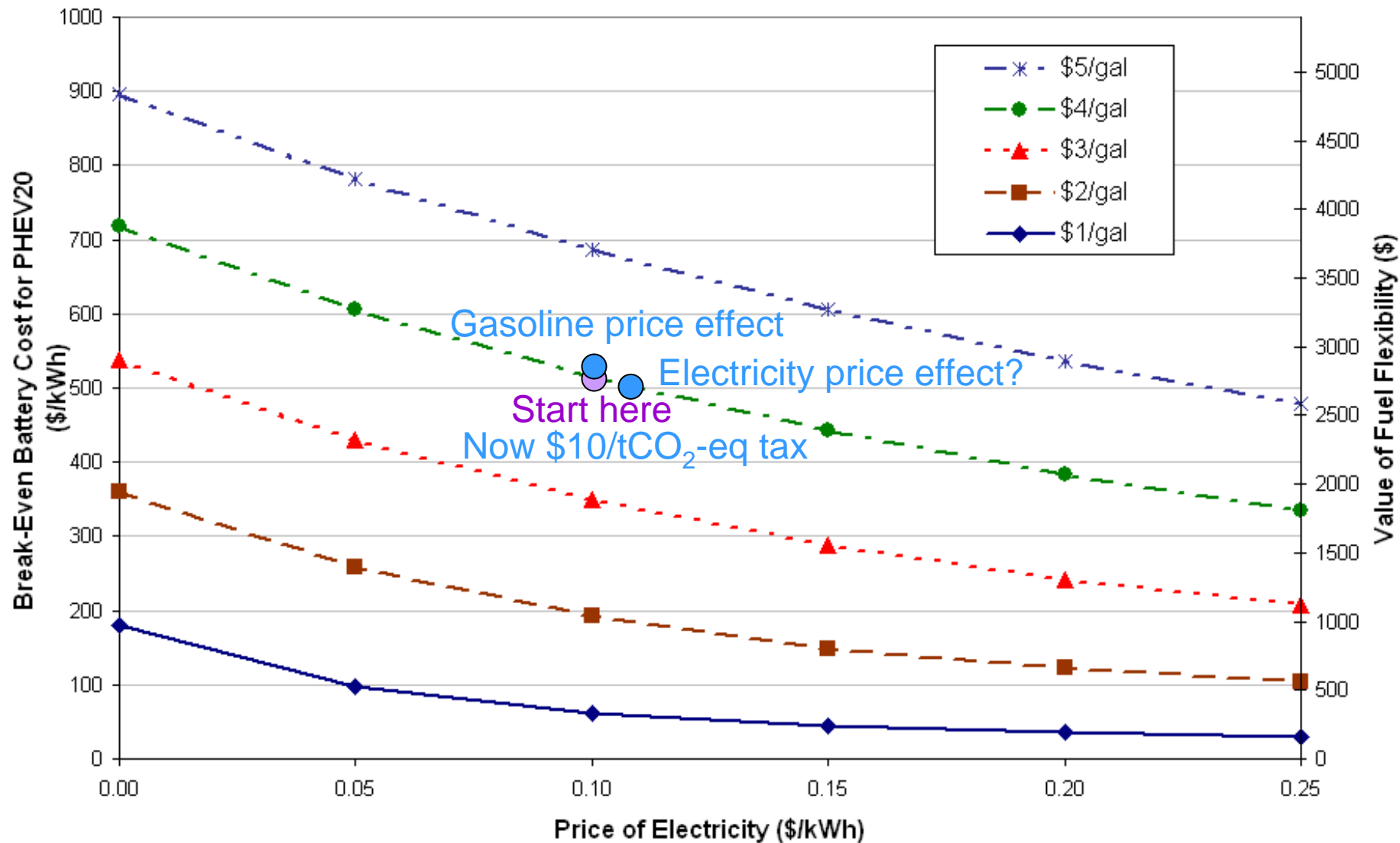
# Typical discounted cash flow analyses reduce apparent battery value by setting price volatility to zero.



# Implications for Climate Policy

# PHEV purchase economics are sensitive to the price of electricity. A carbon price may not incentivize PHEVs, and off-peak rates may matter.

Varying the mean long-term price of gasoline and the constant price of electricity in the one-factor model with the baseline parameter values



# First-order analyses show that subsidizing PHEVs may be expensive.

- Governments may want to subsidize PHEVs because charge-depleting operation may emit fewer greenhouse gases.
- Even if purchasers use a real options framework to value efficiency benefits, the needed government subsidies could imply carbon valuations of  $> \$100/\text{tCO}_2\text{-eq}$ .
  - This is consistent with estimates in Kammen et al. (2008) that are based on discounted cash flow methods.
- These analyses ignore air pollution co-benefits as well as other benefits PHEVs may have in a climate policy context.

# Implications for Business Models

# Will vehicle purchasers actually value fuel flexibility?

- 1) Fleet purchasers may actually use these real options methods.
- 2) Individual purchasers' under-valuation could open up new business models.

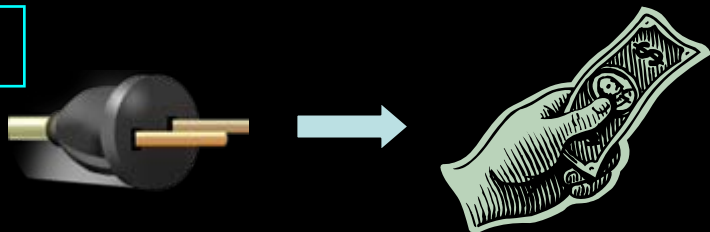
# New business models may speed adoption by restoring value left on the table due to purchasers' failing to value fuel flexibility.

1



A company pays the vehicle owner up front.

2



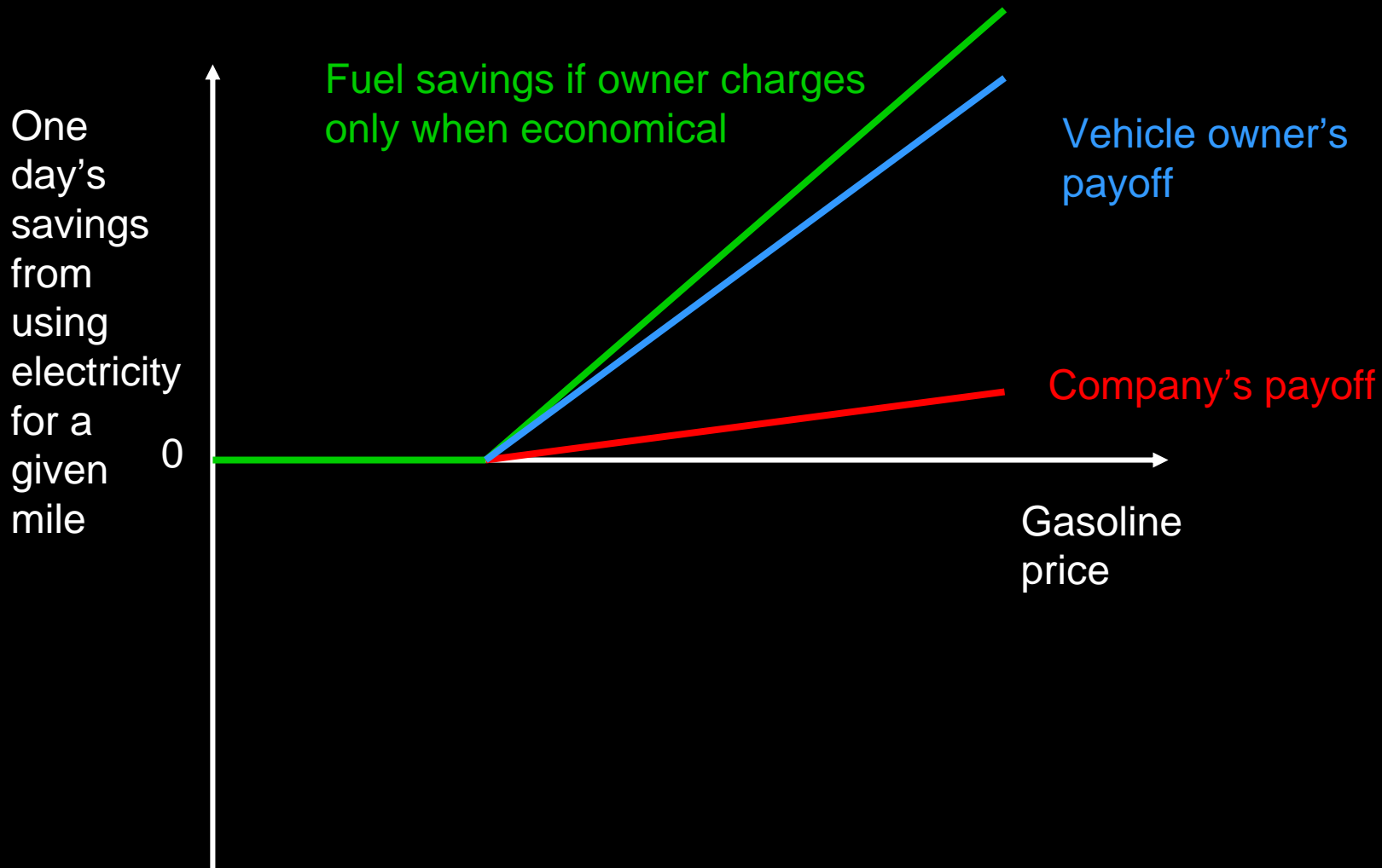
Each time the vehicle owner charges, she pays the company a percentage of the fuel savings.

The company has purchased a percentage of the PHEV options' value.

The company wants to make this deal if the up-front payment is less than the purchased options' value.

The vehicle purchaser may like the deal if the up-front payment is more than the discounted cash flow value of the stream of charging payments.

# This payment plan preserves the incentive to charge when electricity is “cheaper.”



# Conclusions

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- A real options approach can raise the break-even battery price by over \$100/kWh.
- A carbon price might not encourage PHEV adoption, while low off-peak electricity rates could make PHEVs much more attractive.
- Subsidizing PHEVs still seems like an expensive greenhouse gas abatement strategy. However, we need to consider air pollution co-benefits and the abatement flexibility PHEVs give governments.
- New business models for monetizing fuel savings may be profitable to both the vehicle purchaser and the vehicle seller and could speed adoption of multi-fuel vehicles.

- Thanks to Dan Kammen and Alex Farrell.
- For an overview of these ideas, please see the November 2008 issue of the USAEE's *Dialogue* at <http://www.usaee.org/pdf/Nov08.pdf>.
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