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Quantifying Adoption Rates and Energy Savings Over Time for Advanced Manufacturing Technologies

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Prospective energy savings from advanced technologies

- An advanced manufacturing technology can offer significant energy savings, but only after the technology is adopted by industry.
- Neglecting the technology adoption rate risks over-estimating the prospective energy savings.
- With advanced technology adoption rates, we can:
  - Prioritize efforts to roll out new technologies by knowing which technologies offer the largest energy savings over time
  - Target additional commercialization and development efforts towards technologies with high potential benefits but low adoption rates

Prospective energy savings from advanced technologies

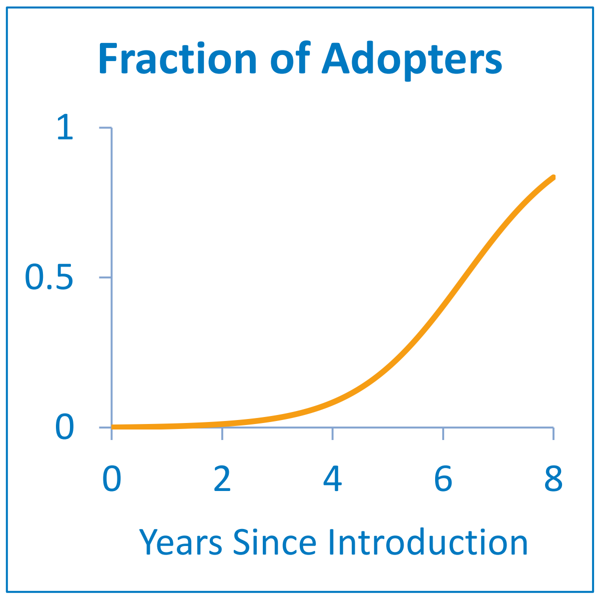
- Technology adoption rates are generally extrapolated from 3 – 5 years of adoption data.
- Want to avoid:
    - Waiting on adoption data
    - Introducing uncertainty via extrapolation

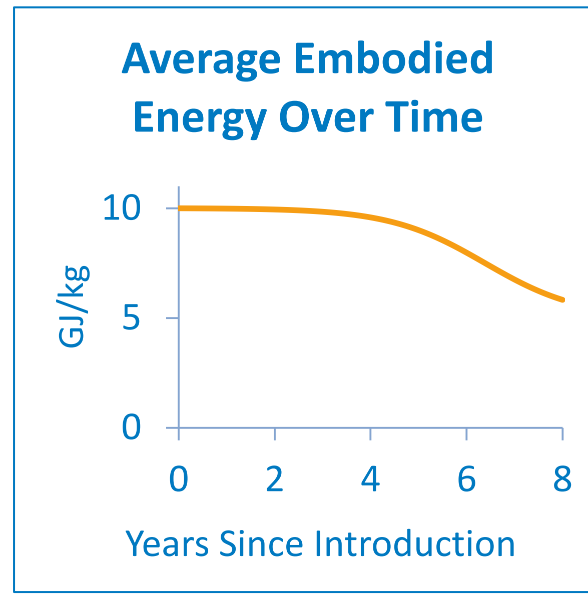
- How can we predict technology adoption rates for advanced technologies that are just reaching the market?

Objective: Estimate energy savings over time

Technology-specific data → Bass diffusion curves → Energy use over time

Technology Characteristic	Data
Payback period	3 years
Type of modification	Add-on
Lifetime	8 years
and other characteristics	





Method overview

- Convert technology characteristic data into technology adoption score, s_t
  - Eleven technology characteristics (listed on next slide)
- Use the adoption score to estimate Bass diffusion model parameters q and p for each technology
  - Several methods for parameter estimation
  - Current adoption fraction data used to shift Bass curve to the left
- Combine the Bass curve with energy savings information to obtain industry-average energy use over time as the technology is adopted

Technology characteristics and attributes

<table>
<tr><th colspan="2">Characteristics</th><th colspan="12">Technology Attributes</th></tr>
<tr><td rowspan="4">Relative advantage</td><td>Internal rate of return</td><td colspan="4">< 10%</td><td colspan="4">10 – 30%</td><td colspan="4">> 30%</td></tr>
<tr><td>Payback period</td><td colspan="3">> 8 years</td><td colspan="3">5 – 8 years</td><td colspan="3">2 – 4 years</td><td colspan="3">< 2 years</td></tr>
<tr><td>Initial expenditure</td><td colspan="4">> 10% of investment budget</td><td colspan="4">0.5 – 10% of investment budget</td><td colspan="4">< 0.5% of investment budget</td></tr>
<tr><td>Non-energy benefits</td><td colspan="3">Negative</td><td colspan="3">None</td><td colspan="3">Small</td><td colspan="3">Large</td></tr>
<tr><td rowspan="4">Technical context</td><td>Distance to core process</td><td colspan="6">Core process</td><td colspan="6">Ancillary process</td></tr>
<tr><td>Type of modification</td><td colspan="3">Substitution</td><td colspan="3">Replacement</td><td colspan="3">Add-on</td><td colspan="3">Organization</td></tr>
<tr><td>Scope of impact</td><td colspan="6">System-wide</td><td colspan="6">Local or component</td></tr>
<tr><td>Lifetime</td><td colspan="3">> 20 years</td><td colspan="3">5 – 20 years</td><td colspan="3">< 5 years</td><td colspan="3">Not relevant</td></tr>
<tr><td rowspan="3">Information context</td><td>Transaction costs</td><td colspan="4">> 50% of initial expenditure</td><td colspan="4">10 – 50% of initial expenditure</td><td colspan="4">< 10% of initial expenditure</td></tr>
<tr><td>Knowledge for planning and implementation</td><td colspan="4">Technology expert</td><td colspan="4">Engineering personnel</td><td colspan="4">Maintenance personnel</td></tr>
<tr><td>Sectoral applicability</td><td colspan="6">Process</td><td colspan="6">Cross-cutting</td></tr>
</table>

Source: Fleiter, Hirzel and Worrell, *Energy Policy*, 2012

Technology characteristics and attributes

<table>
<tr><th colspan="2">Characteristics</th><th colspan="12">Technology Attribute Rankings</th></tr>
<tr><td rowspan="4">Relative advantage</td><td>Internal rate of return</td><td colspan="4">0</td><td colspan="4">1</td><td colspan="4">2</td></tr>
<tr><td>Payback period</td><td colspan="3">0</td><td colspan="3">1</td><td colspan="3">2</td><td colspan="3">3</td></tr>
<tr><td>Initial expenditure</td><td colspan="4">0</td><td colspan="4">1</td><td colspan="4">2</td></tr>
<tr><td>Non-energy benefits</td><td colspan="3">0</td><td colspan="3">1</td><td colspan="3">2</td><td colspan="3">3</td></tr>
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<tr><td>Sectoral applicability</td><td colspan="6">0</td><td colspan="6">1</td></tr>
</table>

Source: Fleiter, Hirzel and Worrell, *Energy Policy*, 2012

Convert characteristic data to adoption score s_t

	Characteristics	Technology Ranking r_{ct}	Maximum Ranking $r_{c,max}$	Characteristic Weights w_c
Relative advantage	Internal rate of return	1	2	0.08
	Payback period	2	3	0.13
	Initial expenditure	0	2	0.16
	Non-energy benefits	3	3	0.06
Technical context	Distance to core process	1	1	0.09
	Type of modification	2	3	0.09
	Scope of impact	0	1	0.08
	Lifetime	3	3	0.09
Information context	Transaction costs	2	2	0.05
	Knowledge for planning and implementation	1	2	0.09
	Sectoral applicability	0	1	0.08

Fleiter, Hirzel and Worrell, *Energy Policy*, 2012

Score Calculation:

$$s_t = \sum_c w_c \frac{r_{ct}}{r_{c,max}}$$

$$c \in \{\text{characteristics}\}$$
$$t \in \{\text{technologies}\}$$

$$0 \leq s_t \leq 1$$

s_t closer to 1 ⇒ faster adoption

Bass diffusion curves and parameters

- Bass diffusion curves model technology adoption over time as a function of two parameters
  - **Coefficient of imitation** (p): Effect of advertising, other external influences
  - **Coefficient of innovation** (q): Word of mouth, competition between users
- Alternative parameterizations may use
  - Years to 95% technology adoption (t_{95})
  - Coefficient ratio ($^{q}/_{p}$)

Methods for converting s_t to Bass curve parameters

- All methods involve converting one piece of information (s_t) into two pieces of information (q, p)
- Fixed parameter values are calculated from technology adoption dataset collected by Argonne National Laboratory

Method	Fixed Parameter	Fixed Parameter Measure	Score determines …	Calculated Parameter(s)
1	p	Median	q	n/a
2	q/p		q	p
3	q/p		$t_{95\%}$	q and p
4	q/p		$q+p$	q and p

- Can't determine an "objectively" best method
- Results from different methods are similar

Convert s_t to q and p

- Need relationship between the adoption score s_t and the parameter being estimated
- Create bins for s_t: each bin corresponds to one observed value of the parameter
  - Applies to any parameter being estimated

Example: s_t bins for estimating q

q observations	1.4	1.1	0.8	0.7	0.4
s_t bins	[1, 0.8)	[0.8, 0.6)	[0.6, 0.4)	[0.4, 0.2)	[0.2, 0]

Example: s_t bins for estimating $t_{95\%}$

$t_{95\%}$ observations (years)	8	11	15	15	21
s_t bins	[1, 0.8)	[0.8, 0.6)	[0.6, 0.4)	[0.4, 0.2)	[0.2, 0]

Obtain technology characteristic data

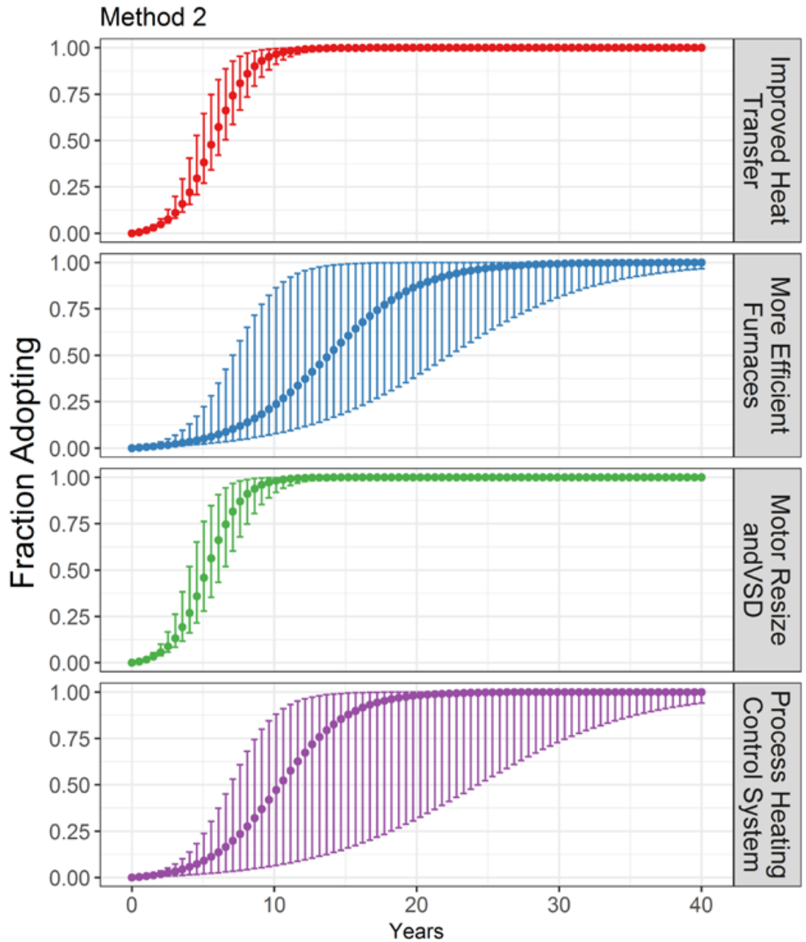
	Characteristics	Glass Industry Technologies: Re-sized motors and/or VSDs	More efficient furnaces	Improved heat transfer and containment	Process heating control systems
Relative advantage	Internal rate of return	1	1	2	1
	Payback period	3	3	3	3
	Initial expenditure	2	0	1	1
	Non-energy benefits	2	2	1	2
Technical context	Distance to core process	1	0	1	0
	Type of modification	1	1	2.25	1
	Scope of impact	1	1	1	0
	Lifetime	1	1	1	1
Information context	Transaction costs	2	1	2	0
	Knowledge for planning and implementation	2	0	1.5	1
	Sectoral applicability	1	0.5	1	1
	Diffusion progress	0.85	0.2	0.85	0.85

Reminder: A higher rank indicates an attribute that leads to faster adoption.

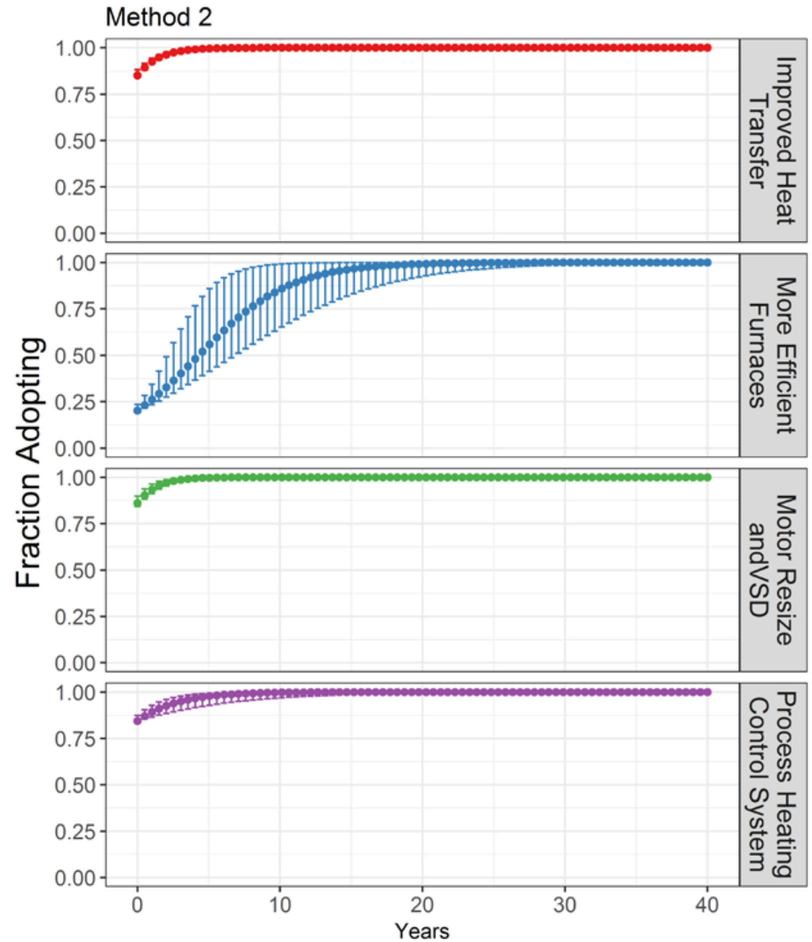
Sources: Worrell et al. (2008), Worrell et al. (2010), 2017 DOE Glass Product Bandwidth Study

Results: Bass curves for individual technologies

Neglecting current diffusion progress



With current diffusion progress



Error bars obtained from sensitivity analysis on w_c (characteristic weight) values

Bass curves to energy use and savings

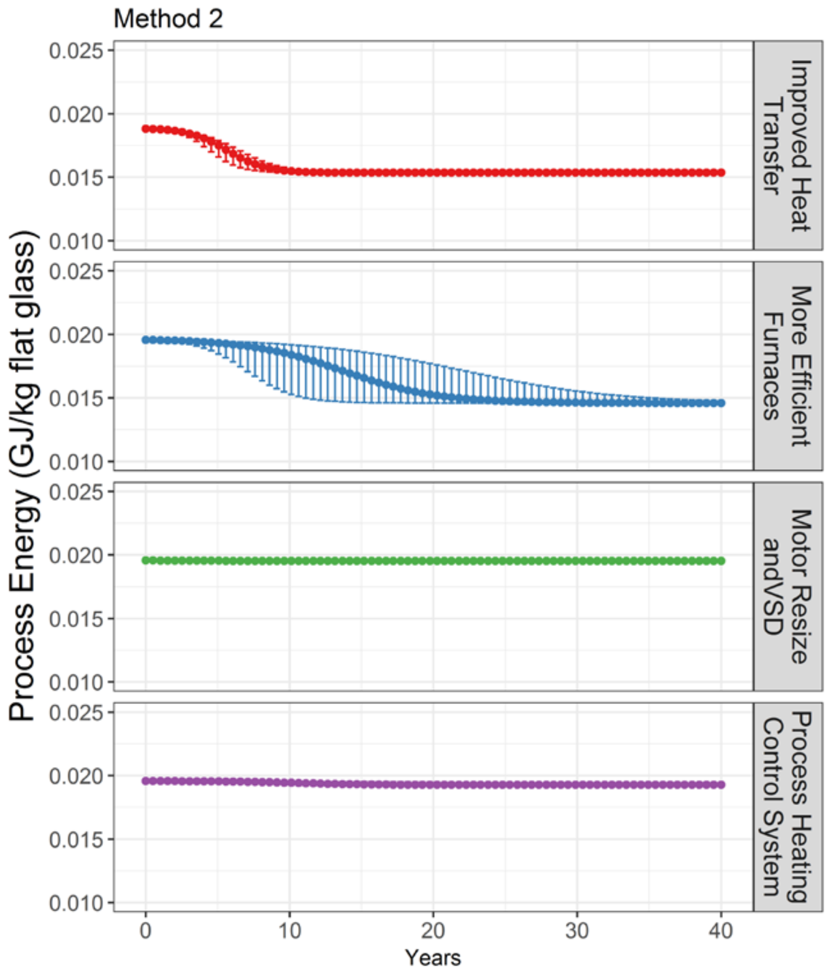
- Each technology reduces energy use in one or more sub-processes

Technology	Sub-process	Fuel	Percent Savings
Motor Re-sizing and VSDs	Batch preparation	Electricity	12%
More Efficient Furnace	Melting and Refining	Natural gas	55%
		Electricity	-133%
Improved Process Heat Control		Natural gas	3%
Improved Heat Transfer		Natural gas	20%
	Forming	Natural gas	20%
	Annealing	Natural gas	20%
	Tempering	Fuel oil	20%
	Autoclave	Natural gas	20%

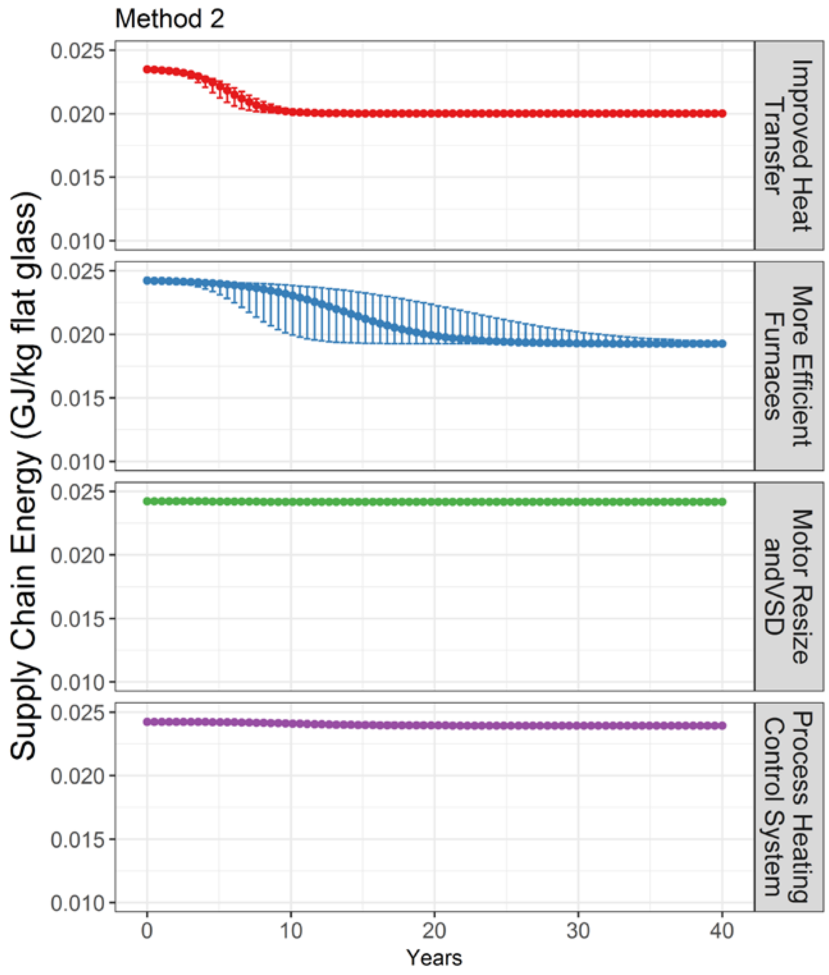
Sources: Worrell et al. (2008); DOE Glass Bandwidth Study (2017)

Results: Industry-average energy over time, from adoption of individual technologies

Process energy

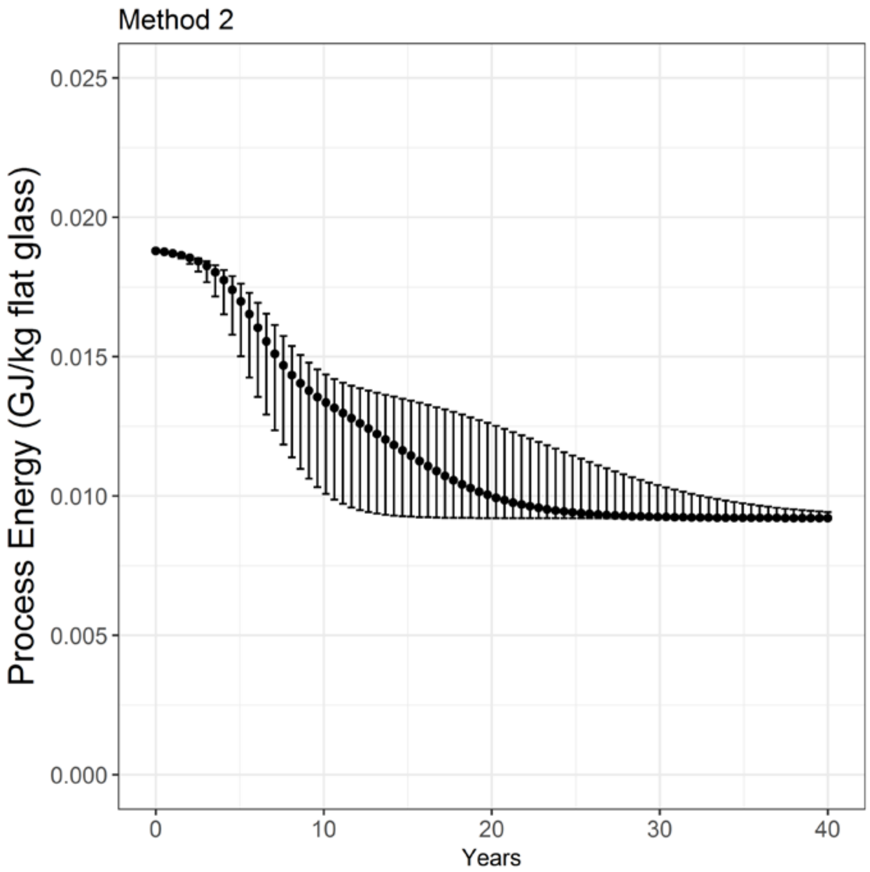


Supply chain energy

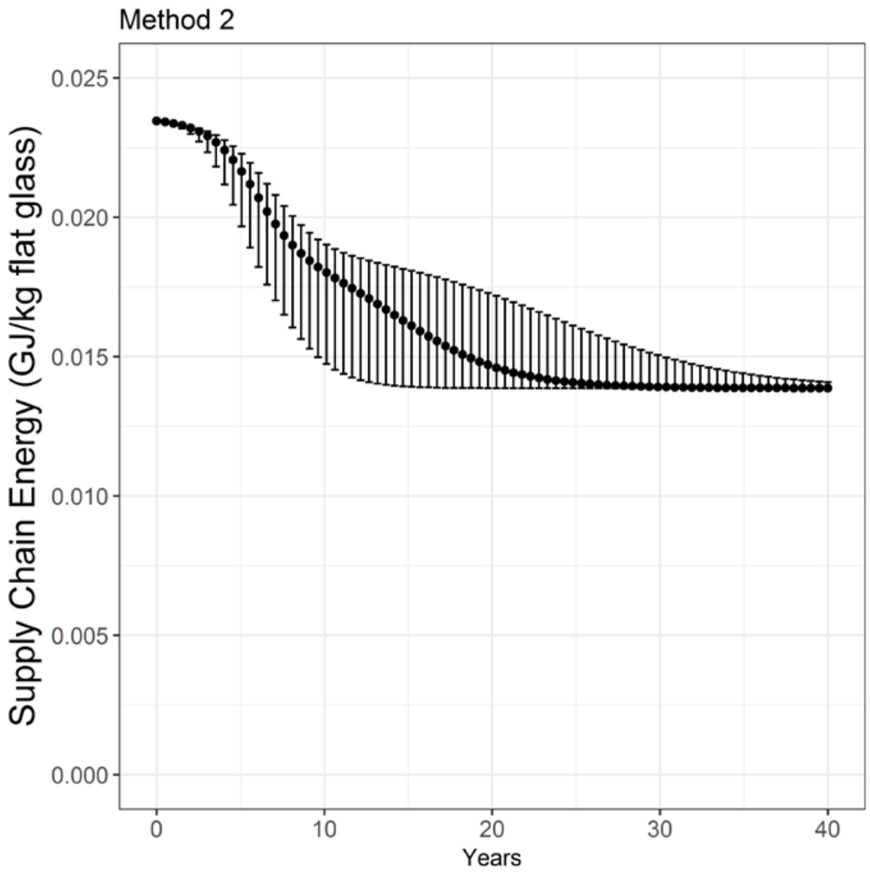


Results: Industry-average energy over time, from simultaneous adoption of all technologies

Process energy



Supply chain energy



Conclusion and Next Steps

- Method for projecting energy savings over time from adoption of advanced technologies
- Enhances prospective studies by accounting for different technology adoption rates and resultant energy savings
- Uncertainties exist but can be dealt with through sensitivity analysis

Next Steps

- Test sensitivity to fixed measure used in parameter calculations
- Estimate cumulative energy savings using projections of annual glass production
- Validate method results using historical adoption data

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General Sources

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Technology Adoption Data Set

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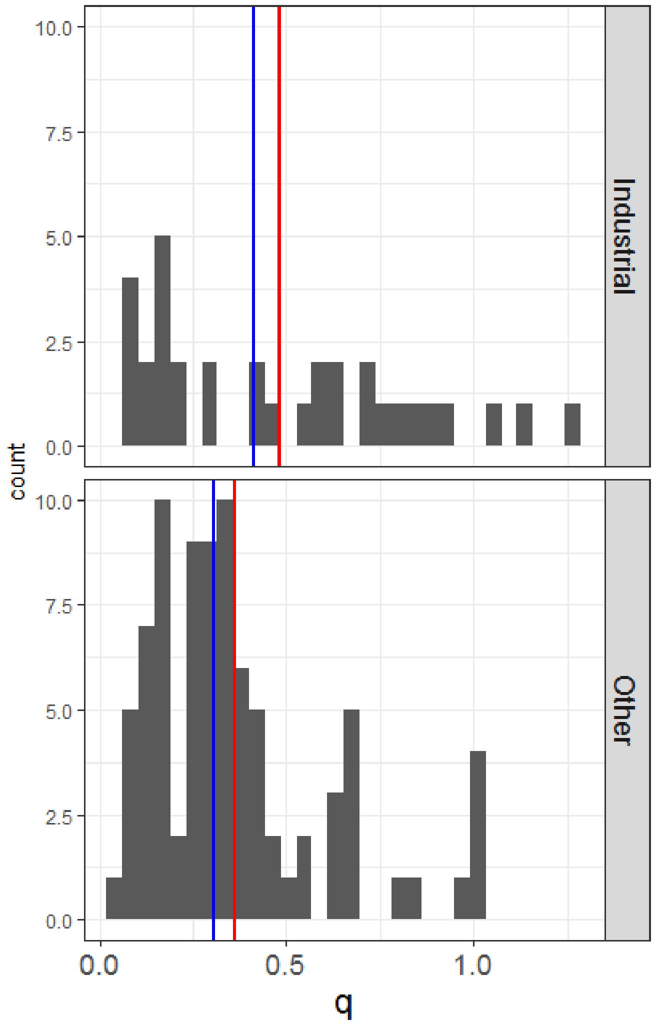
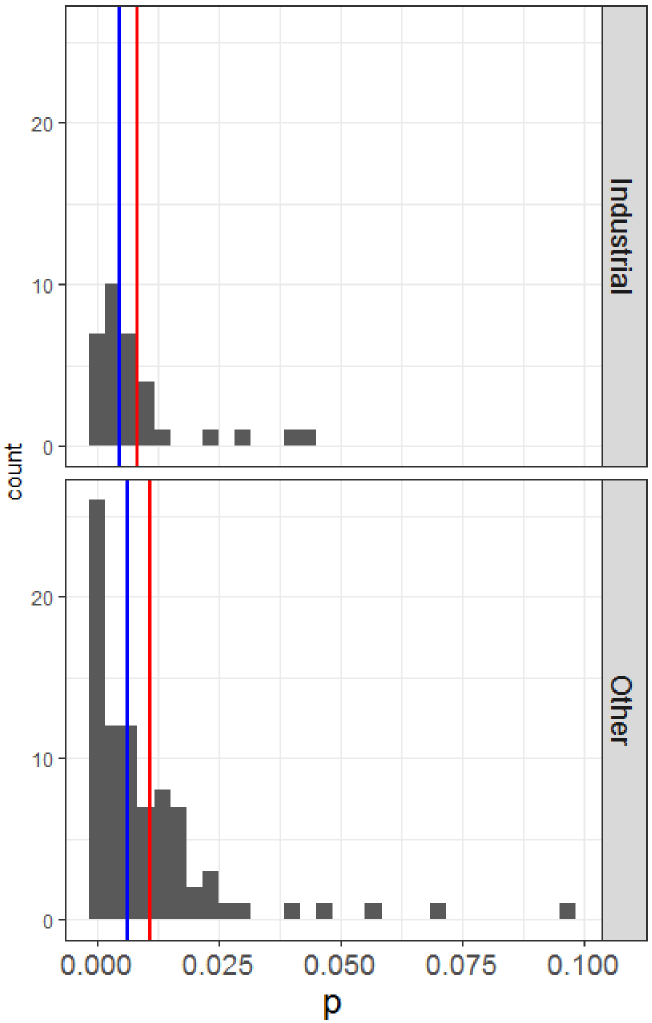
Additional Slides

Relevant Data

Histogram of q parameter values



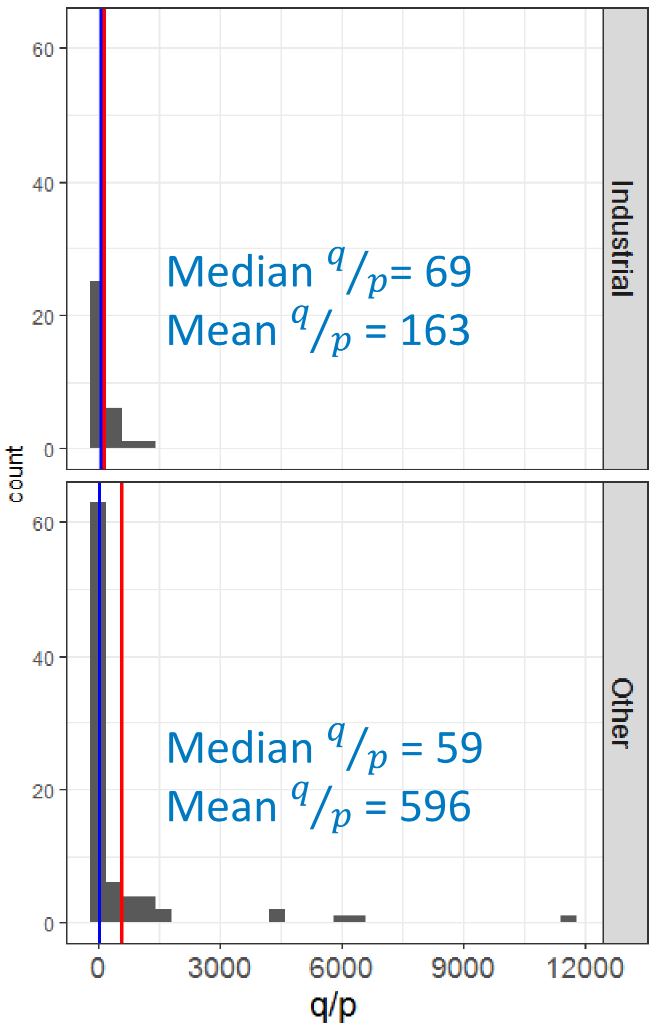
Histogram of p parameter values



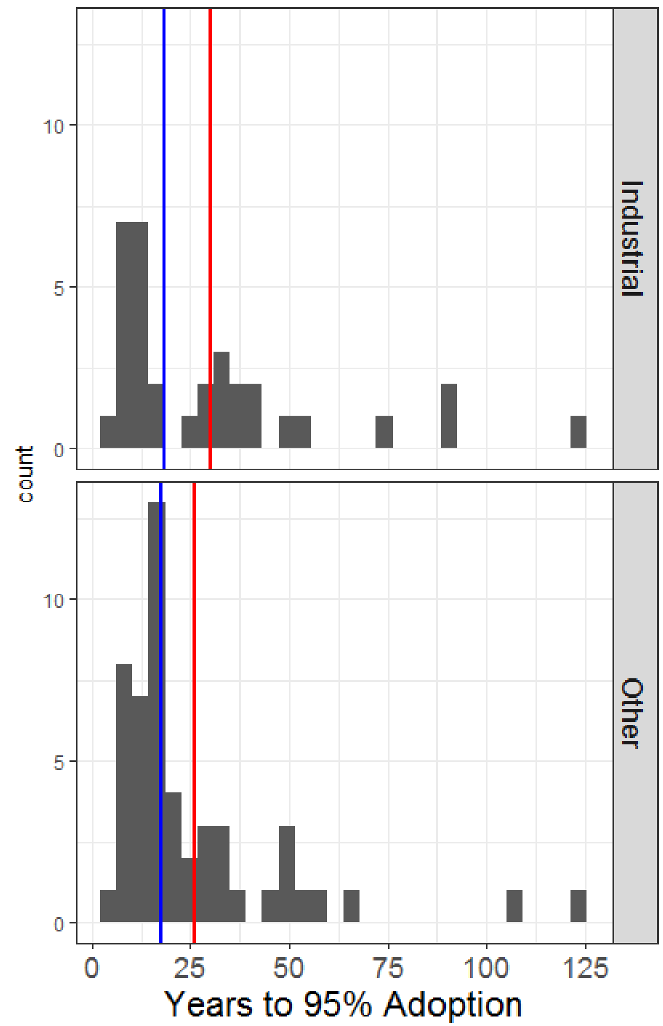
Blue lines indicate median values, red lines indicate mean values

Relevant Data

Histogram of $^{q}/_{p}$ values



Histogram of $t_{95\%}$ values



Blue lines indicate median values, red lines indicate mean values