

**Adoption of energy efficiency measures for non-  
residential buildings**  
:  
**Technological and organizational heterogeneity in  
the commercial and services sector**

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# Academic opportunity

## Empirical barriers literature

- Qualitative studies
  - Tend to focus on one EEM (class)
- Quantitative studies
  - Small sample sizes
  - Tend to aggregate different types of EEMs
  - Suffer from hypothetical bias
  - Biased toward core-process measures

# Opportunity

- Germany
- Representative, large-sample survey
  - Spring 2014
- Commercial & Services Sector
- $N = 2440$
- Piggy back survey:  
(Barriers to) adoption of EEMs



# Practical stake

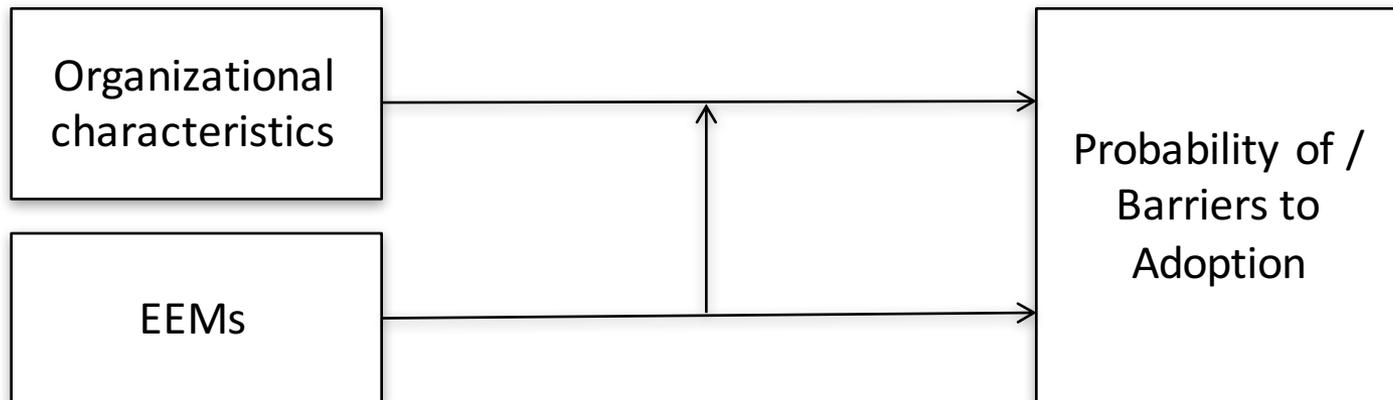
## Alleged **Efficiency Gap** in Commercial and Services Sector

- OECD:
  - Growing but lagging manufacturing in efficiency improvements (OECD) (Mulder et al. 2014)
- Germany:
  - 16% of energy end-use (AGEB 2015)
  - 141 PJ efficiency gap in 2030 (IFEU et al. 2011)
  - Mostly in auxiliary, building-related measures: lighting, insulation, heating systems (IFEU et al. 2011)
- US:
  - Efficiency gap commercial buildings 10-20% (PNNL 2009)



# Objective

- Role of technological and organizational heterogeneity in adoption and barriers to adoption of Energy Efficiency Measures (EEMs)



# Research set-up

- 4 EE Measures

- Cross-cutting
- Building-related
- Ancillary
- Not too specific
- Yet, heterogeneous



1. Efficient Lighting

- Adoption and barriers

- Did you adopt? → Full sample
- If **no**: did you consider? → Elim. hypoth. bias
- If **yes**: which of 13 barriers relevant to your not adopting?

- Company demographics

- Levels of analysis

- Firm, subsidiary, branch
- Individual measures

## Econometric analyses



2. Insulation of the Building Envelope



3. Heating System Replacement



4. Optimization of Heating System Operations



# Dimensions of heterogeneity

Variable	Obs.	Mean	Std. Dev.	Min.	Max.
<b><i>Adoption</i></b> since 2008 (1 = adopted, 0 = not adopted)					
Lighting	1243	<b>0,28</b>	0,45	0	1
Insulation	1238	<b>0,07</b>	0,26	0	1
Heating replacement	1089	<b>0,08</b>	0,28	0	1
Heating operations	1166	<b>0,10</b>	0,31	0	1
<b><i>Organizational attributes</i></b> (1 = yes, 0 = no)					
Tenant	2440	<b>0,53</b>	0,50	0	1
Subsidiary	2440	<b>0,16</b>	0,37	0	1
Energy management system	2347	<b>0,11</b>	0,31	0	1
Energy manager	2381	<b>0,11</b>	0,31	0	1
Audit	2304	<b>0,14</b>	0,34	0	1



# Barriers

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<b>Barrier category</b>	<b>Barrier in questionnaire</b>
Split incentives	Building(s)/space(s) are rented or leased
Access to capital	Lack of access to capital
Profitability/financial risk	Uncertain energy and/or technology prices Too high investment costs The measure is uneconomical The system is already efficient
Technical risk	Risk of negative impact on product quality Technical risk of interference with the production process
Organizational factors	Other investment priorities Lack of time Postponed due to ongoing reorganization Internal disagreement about adoption of the measure Lack of internal know-how

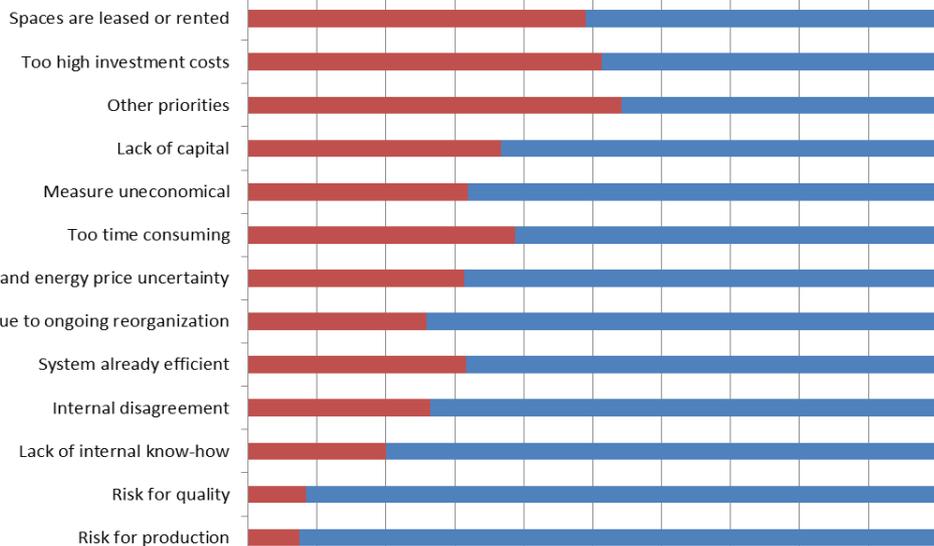
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### Lighting

Percentage of respondents stating a barrier as relevant

0% 10% 20% 30% 40% 50% 60% 70% 80% 90% 100%



■ yes ■ no

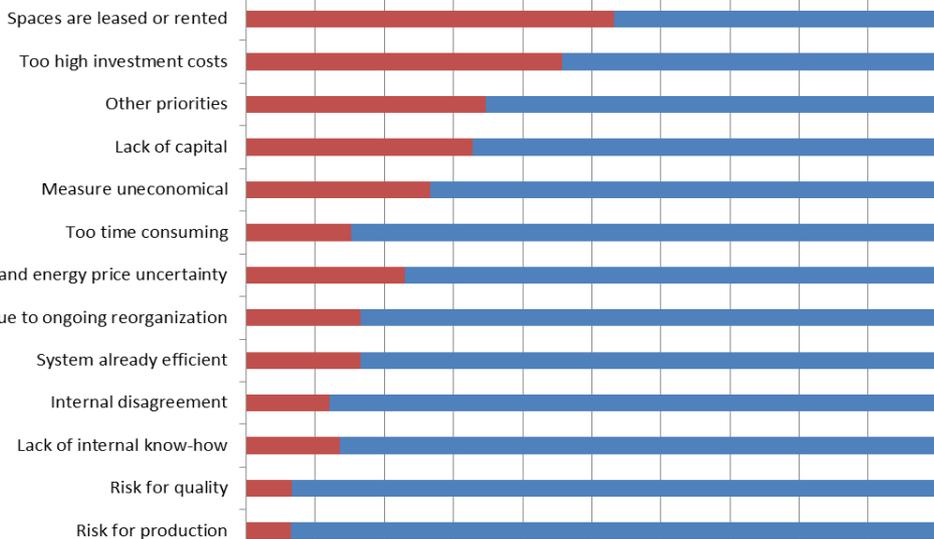
### Insulation

0% 10% 20% 30% 40% 50% 60% 70% 80% 90% 100%



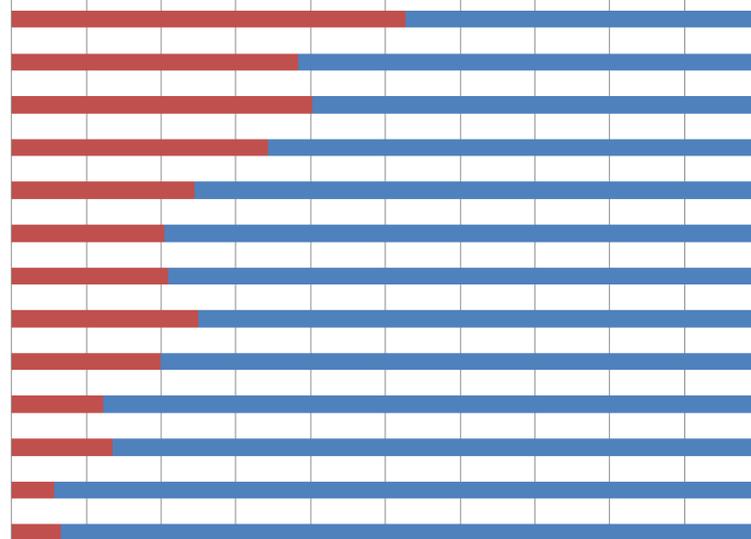
### Heating system replacement

0% 10% 20% 30% 40% 50% 60% 70% 80% 90% 100%



### Optimization of heating system operations

0% 10% 20% 30% 40% 50% 60% 70% 80% 90% 100%



# Two sets of models

1a.  $\Pr(\text{Adoption})_{ij} = \alpha + \boldsymbol{\beta}'\mathbf{EEM}_j + \boldsymbol{\gamma}'\mathbf{x}_i + \boldsymbol{\delta}'\mathbf{z}_i + \varepsilon_{ij}$

- Random Effects Probit
- $\mathbf{x}_i$ : vector of organizational characteristics
- $\mathbf{z}_i$ : vector of control variables
- $\mathbf{EEM}_j$  dummies for individual EEMs
- $j = \text{EEM } 1, \dots, 4$

1b.  $\Pr(\text{Adoption})_{ij} = \alpha_j + \boldsymbol{\gamma}_j'\mathbf{x}_i + \boldsymbol{\delta}_j'\mathbf{z}_i + \varepsilon_{ij}$

- Single Probits

2.  $\Pr(\text{Barrier})_{ik} = \alpha_k + \boldsymbol{\beta}_k'\mathbf{EEM}_i + \boldsymbol{\gamma}_k'\mathbf{x}_i + \boldsymbol{\delta}_k'\mathbf{z}_i + \varepsilon_{ik}$

- Single Probits
- $k = \text{barrier } 1, \dots, 13$

Robustness: multivariate probits

# Results: Adoption (avg. marginal effects)

Variables	RE probit	Single probits			
	Any EEM	Lighting	Insulation	Heating replacement	Heating operations
Lighting <sup>a</sup>	0.115 ***				
Insulation <sup>a</sup>	-0.021 *				
Heating replacement <sup>a</sup>					
Tenant					-0.050 ***
Subsidiary	-0.033 **	-0.081 **	-0.054 *		
Energy management system					
Environmental/energy manager	0.048 **	0.124 *	0.054 **		
Elec. cost per employee (*1000 EUR)					0.011 *
ln(number of employees)			-0.013 *		0.028 ***
Electricity rate (EUR/kWh)	0.330 ***	0.669 ***			0.533 ***
Heating system external	-0.039 ***			-0.111 ***	-0.065 ***
Decentralized, clean energy used	0.066 ***	0.156 ***			0.062 **
Sector dummies	✓	✓	✓	✓	✓
Observations	3676	975	971	843	887

<sup>a</sup> omitted category: Heating operations

\*\*\* p<0.01, \*\* p<0.05, \* p<0.1



# Results: Barriers (avg. marginal effects)

Variables	Spaces are rented	Lack of capital	Tech/e-price uncertainty	Investment costs	Already efficient	Investment priorities	Time consumption	Postponed due to reorg	Internal disagreement	Lack of know-how
Lighting <sup>a</sup>	-0.089**		0.121***	0.118**	0.127***	0.134***	0.163***		0.127***	
Insulation <sup>a</sup>			-0.109**		-0.083*			-0.102**		
Heating replacement <sup>a</sup>						-0.085*				
Tenant	0.378***	-0.140***	-0.159***	-0.227***	-0.168***	-0.170***	-0.117**			
Subsidiary		-0.121**								
Energy management system										
Environmental/energy manager									0.128*	
Energy audit	-0.146***			0.138*		0.123*				
Elec. cost per employee (*1000 EUR)		-0.038**		-0.067***		-0.046**	-0.031*	-0.072***	-0.034**	-0.030**
ln(number of employees)						0.042*				
Electricity rate (EUR/kWh)			0.728*						-0.723*	
Heating system external	0.072***	-0.196***	-0.111**	-0.230***		-0.185***	-0.160***	-0.187***	-0.107***	-0.094**
Decentralized, clean energy used			-0.296**							
Sector dummies	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Observations	486	484	477	485	451	489	483	483	479	470

<sup>a</sup> omitted category: Heating operations

\*\*\* p<0.01, \*\* p<0.05, \* p<0.1

# Conclusions

- The effect of organizational characteristics on adoption varies by EEM
- EEM heterogeneity consistent with theory on adoption of innovations
- Heterogeneity of EEMs has little impact on barrier rankings
  - Owner-user dilemma, investment costs, and priorities most relevant
  - Technical risk least relevant
- Lighting stands out from space heating measures
  - Less susceptible to owner-user dilemma
  - lower investment costs
  - closer to core process
- Owner-user dilemma perceived most relevant for rejection, but absence not necessarily strong predictor of adoption.
- Energy manager antecedent of and integral to EMS.
  - Consistent with literature on environmental management
  - Energy management  $\leftarrow + \rightarrow$  Adoption

# Support for policies

- Audits
  - Overcome landlord-tenant dilemma through mitigation of asymmetric information
- ESCOs
  - Bundling of risk and rewards in one actor
  - Promote from low-priority issue to core business
  - Energy Performance Contracting
- Find new homogeneity in expanded geographical scope
  - Central information repositories





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Characteristics		Attributes			
Relative advantage	Internal rate of return	Low ( < 10% )		Medium ( 10 - 30% )	High ( > 30% )
	Payback period	Very long ( > 8 years )	Long ( 5-8 years )	Medium ( 2-4 years )	Short ( < 2 years )
	Initial expenditure	High ( > 10% of invest. budget )		Medium ( 0.5-10% of invest. budget )	Low ( < 0.5% of invest. budget )
	Non-energy benefits	Negative	None	Small	Large
Technical context	Distance to core process	Close ( Core process )		Distant ( Ancillary process )	
	Type of modification	Technology substitution	Technology replacement	Technology add-on	Organizational measure
	Scope of impact	System ( system-wide effects )		Component ( local effects )	
	Lifetime	Long ( > 20 years )	Medium ( 5-20 years )	Short ( < 5 years )	Not relevant
Information context	Transaction costs	High ( > 50% of in. expenditure )		Medium ( 10–50% of in. expenditure )	Low ( < 10% of in. expenditure )
	Knowledge for planning and implementation	Technology expert		Engineering personnel	Maintenance personnel
	Diffusion progress	Incubation ( 0% )	Take-off ( < 15% )	Saturation ( > 85% )	Linear ( 15-85% )
	Sectoral applicability	Process related		Cross-cutting	
		Lower adoption rate		Higher adoption rate	

Fig. 1. Classification scheme for EEMs.

# Subsectors

