Residential District Heating Demand in Denmark: Empirical Evidence Using Dynamic and Static Panel Approaches

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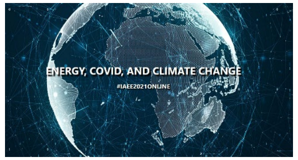

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1. Background and Motivation

- Denmark has one of the most developed district heating networks worldwide, which provides heat (both for space heating and hot water consumption) to almost two thirds of its households.
- In 2019, district heating consumption in the residential sector alone represented 11% of Danish final energy consumption; 57.6% of district heating was produced by biomass.
- A higher demand for district heating coupled with higher shares of renewable energy in the power sector is expected in the near future.
- Reducing residential district heating demand while accelerating the transition towards clean energies is crucial for meeting the ambitious Denmark's climate goals.
- The recent focus of the Danish government on the green tax reform as the centerpiece of climate efforts, which could substantially alter the district heating market, has elevated the importance of characterizing district heating demand behavior.
- Carbon tax from 177 DKK per ton (approx. 23 euros) to 1,500 DKK (approx. 200 euros) – if the government follows the recommendation of the Danish Council on Climate Change.
- Knowing the magnitude of the demand response to increasing district heating prices allows predicting the effect of the carbon tax and its distributional impacts.

2. Objectives

- To estimate price and income elasticities of district heating demand in Danish households.
- To investigate the sociodemographic and dwelling characteristics influencing district heating demand.
- To explain heterogeneity in the district heating demand response to price changes across various household types.
- To provide an informed basis for evaluating the effectiveness of price policies (e.g., carbon tax) to reduce district heating consumption as a means to combat climate change.
- To inform future needs and trends in energy demand and supply and improve the design of targeted energy-efficiency policies.

3. Data

- Data are composed of annual district heating consumption of Danish households living in single-family detached houses and price information from 299 utilities.

- Consumption and price data are combined with socioeconomic characteristics and dwelling attributes from Statistics Denmark, derived heating degree days from each municipality's daily average temperature information (Danish Meteorological Institute), and whether a household received a "heating allowance" (a supplement to heating costs granted to pensioners).

- The link between district heating consumption and price data with the administrative records was possible because all people living in Denmark are assigned a unique identification number, "Det Centrale Person Register (CPR), which public authorities use to store personal information on a regular basis.

- The final unbalanced panel data resulting from pre-processing steps (data integration, data cleaning, data selection, and data transformation) consists of 115,502 Danish households and spans from 2015 to 2019.

3. Data

Summary statistics

Variables	Mean	Std Dev	Min	Max
Average yearly district heating energy consumption (kWh)	17,543	6,746	7,361	47,657
Average yearly district heating price (DKK per kWh)	0.58	0.14	0.21	1.22
Household disposable income (DKK)	523,349	534,809	1,043	1,42e+08
Household size	2.57	1.22	1	10
Heating allowance	0.07	0.25	0	1
Dwelling years				
Before 1961	0.22	0.41	0	1
1961-1972	0.23	0.42	0	1
1973-1978	0.16	0.36	0	1
1979-1998	0.22	0.41	0	1
1999-2008	0.13	0.33	0	1
After 2008	0.05	0.21	0	1
Living area square footage (m^2)	147	36	80	296
Heating degree days (HDD) 17°C	8.11	0.33	7.20	8.73
Government office region				
Capital Region of Denmark	0.06	0.24	0	1
Region of Southern Denmark	0.29	0.45	0	1
Central Denmark Region	0.06	0.24	0	1
Zealand Region	0.08	0.26	0	1
North Denmark Region	0.20	0.40	0	1

4. Methodology

- We investigate district heating demand in Danish households over 2015-2019 while controlling for district heating prices, household, dwelling, and weather characteristics.

- The two-step system generalized method of moments (GMM) estimator developed for dynamic models of panel data by Blundell and Bond (1998) is employed. The main advantage of Blundell-Bond Two-step system GMM over static models lies in its ability to account for the interdependence of consumption decisions over time (e.g., sluggish appliance stock adjustments, energy-efficient retrofits, and utilization behavior) and to deal with endogeneity issues of average prices.

- For comparison purposes only, we report the results of other dynamic models (Blundell-Bond one-step system GMM, Arellano-Bond one-step difference GMM) and static models (pooled OLS, random effect, fixed effect).

- Consumers gradually react over time to price increases by moving towards the new long-run equilibrium:

$$lny_{i,t} - lny_{i,t-1} = \lambda\,(lny^{*}_{i,t} - lny_{i,t-1}) \quad (1)$$

$y_{i,t}$ = Energy demand, *i* and *t* are the individuals and years index, respectively.
λ = Adjustment speed coefficient bounded between 0 and 1 (if $\lambda = 0$ there is no adjustment; if $\lambda = 1$ the adjustment is immediate)
$y^{*}_{i,t}$ = Long-run equilibrium demand in time period *t*.

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4. Methodology

Using Eq. (1) the district heating demand function is specified as follows:

$$lnDH_{i,t} = a_0 + a_{DH}lnDH_{i,t-1} + a_P lnP_{i,t} + a_{HI}lnHI_{i,t} + a_{Hs}lnHs_{i,t} + a_{DY}DY_{i,t} + a_{LA}lnLA_{i,t} + a_{HA}HA_{i,t} + a_{GO}GO_{i,t} + a_{HDD}lnHDD_{i,t} + a_T T_t + \varepsilon_{i,t} \quad (2)$$

$DH_{i,t}$ = District heating consumption (kWh) from January 1, 2015, to December 31, 2019

$DH_{i,t-1}$ = District heating consumption in period *t-1*

$P_{i,t}$ = Average price of district heating

$HI_{i,t}$ and $HS_{i,t}$ = Household characteristics such as household disposable income and household size, respectively

$DY_{i,t}$ and $LA_{i,t}$ = Vector of dwelling characteristics such as dwelling year and living area square footage

$HA_{i,t}$ = Dummy variable indicating whether a household received heating allowance

$GO_{i,t}$ = Government office regions

$HDD_{i,t}$ = Heating degree days (HDD) for all municipalities

T_t = Time dummy variables

$\varepsilon_{i,t}$ = Disturbance term

5. Results – Static models

	Static models					
Variables	**Pooled OLS**		**Random effect**		**Fixed effect**	
	Coeff.	**Std. error**	**Coeff.**	**Std. error**	**Coeff.**	**Std. error**
Ln(DH price)	-0.797***	(-0.00369)	-0.815***	(-0.00421)	-0.913***	(0.0103)
Ln(household income)	0.026***	(-0.00211)	0.0231***	(-0.00225)	0.00902	(0.007)
Ln(household size)	0.0186***	(-0.00194)	0.0190***	(-0.00205)	0.0250*	(-0.0135)
Ln(living area square footage)	0.395***	(-0.0037)	0.396***	(-0.00397)	0.323***	(-0.0512)
Heating allowance	0.0503***	(-0.00309)	0.0477***	(-0.00325)		
Dwelling year (Ref = Before 1961)						
1961-1972	-0.0832***	(-0.00221)	-0.0826***	(-0.00237)		
1973-1978	-0.133***	(-0.00248)	-0.131***	(-0.00268)		
1979-1998	-0.180***	(-0.00228)	-0.178***	(-0.00245)		
1999-2008	-0.198***	(-0.00275)	-0.198***	(-0.00295)		
After 2008	-0.325***	(-0.00411)	-0.327***	(-0.00441)		
Government office region (Ref = Capital Region of Denmark)						
Region of Southern Denmark	-0.199***	(-0.00341)	-0.211***	(-0.00362)		
Central Denmark Region	-0.230***	(-0.00389)	-0.231***	(-0.00412)		
Zealand Region	-0.0781***	(-0.0039)	-0.0822***	(-0.0042)		
North Denmark Region	-0.287***	(-0.00488)	-0.288***	(-0.00516)		
Ln(HDD)	0.788***	(-0.0344)	0.680***	(-0.0357)	0.457***	(-0.123)
Time dummies	Yes	Yes	Yes	Yes	Yes	Yes
Constant	5.706***	(-0.0739)	5.966***	(-0.0769)	6.614***	(-0.375)
Observations	133,938		133,938		134,162	
R-squared	0.459		0.458		0.363	
R-squared within			0.488		0.493	
R-squared between			0.459		0.358	
Bruschen-Pagan LM test	10068.85***	(0.000)				
Hausman test			677.49***	(0.000)		

5. Results – Dynamic models

	Dynamic models					
Variables	**Blundell-Bond Two-step system GMM**		**Blundell-Bond One-step system GMM**		**Arellano-Bond One-step difference GMM**	
	Coeff.	**Std. error**	**Coeff.**	**Std. error**	**Coeff.**	**Std. error**
Lagged ln(DH consumption)	0.254***	(0.0633)	0.243***	(-0.0632)	0.184***	(0.055)
Ln(DH price)	-0.489***	(0.114)	-0.545***	(-0.106)	-0.367***	(0.119)
Ln(household income)	0.0303***	(0.00841)	0.0290***	(-0.0082)	0.0146	(0.0348)
Ln(household size)	0.0155***	(0.00518)	0.0145***	(-0.00517)	0.0356	(0.0574)
Ln(living area square footage)	0.308***	(0.0368)	0.304***	(-0.0362)	0.338**	(0.162)
Heating allowance	0.0340***	(0.00871)	0.0332***	(-0.00866)		
Dwelling year (Ref = Before 1961)						
1961-1972	-0.065***	(0.00836)	-0.0647***	(-0.00833)		
1973-1978	-0.1***	(0.0131)	-0.0995***	(-0.0129)		
1979-1998	-0.14***	(0.0173)	-0.138***	(0.0170)		
1999-2008	-0.158***	(0.0194)	-0.156***	(0.0191)		
After 2008	-0.236***	(0.0300)	-0.233***	(0.0294)		
Government office region (Ref = Capital Region of Denmark)						
Region of Southern Denmark	-0.116***	(0.0274)	-0.127***	(0.0256)		
Central Denmark Region	-0.143***	(0.0293)	-0.156***	(0.0276)		
Zealand Region	-0.0381***	(0.0115)	-0.0408***	(0.0114)		
North Denmark Region	-0.192***	(0.0447)	-0.211***	(0.0417)		
Ln(HDD)	0.682***	(0.140)	0.730***	(0.136)	0.253	(0.376)
Time dummies	Yes		Yes		Yes	
Constant	3.795***	(0.376)	3.822***	(0.376)		
Number of observations	12,662		12,662		1,209	
Number of instruments	25		25		14	
Arellano-Bond test for AR(1)	$z = -2.5; p = 0.0125$		$z = -2.45; p = 0.014$		$z = -2.24; p = 0.025$	
Arellano-Bond test for AR(2)	$z = -1; p = 0.316$		$z = -1.02; p = 0.308$		$z = -1.09; p = 0.277$	
Hansen test of overid. restrictions	$\chi^2(5) = 8.28; p = 0.141$		$\chi^2(5) = 8.28; p = 0.141$		$\chi^2(5) = 5.07; p = 0.407$	
Long-run price elasticity	-0.66***	(0.156)	-0.72***	(0.145)	-0.45***	(0.152)

5. Results – Heterogeneous effects

	Ln(DH price)		Lagged ln(DH consumption)		Long-run price elasticity		Number of observations
	Coeff.	Std. error	Coeff.	Std. error	Coeff.	Std. error	
Household disposable income							
Low-income household	-0.569**	(0.246)	0.338**	(0.142)	-0.86**	(0.359)	4,912
High-income household	-0.435***	(0.158)	0.26***	(0.787)	-0.588***	(0.227)	4,313
District heating consumption							
Low consumption	-0.236	(0.189)	0.246	(0.228)	-0.313	(0.293)	5,241
High consumption	-0.53***	(0.16)	0.136	(0.205)	-0.614***	(0.196)	5,538
Dwelling tenure							
Owned	-0.494***	(0.114)	0.27***	(0.66)	-0.677***	(0.16)	11,795
Rented	-0.776	(0.936)	0.112	(0.348)	-0.875	(1.03)	782
Gender							
Single female household	-0.092	(0.357)	0.393	(0.25)	-0.152	(0.612)	1,319
Single male household	-0.656	(0.57)	0.169	(0.089)	-0.668	(0.565)	999
Household type							
Single (both female and male households)	-0.34	(0.302)	0.3	(0.161)	-0.486	(0.46)	2,318
Couple (with and without children)	-0.455***	(0.115)	0.24***	(0.673)	-0.599***	(0.155)	9,953
Dwelling age							
Older dwellings (built before 1961, label between D and G)	-0.371***	(0.136)	0.068	(0.089)	-0.399***	(0.15)	2,499
Newer dwellings (built after 1998, label between A and C)	-0.316*	(0.19)	0.4***	(0.146)	-0.527	(0.354)	2,129
...Location, etc.							

6. Takeaways

- The empirical analysis has offered insight into the characteristics of households having an influence on district heating consumption, the price elasticities of residential demand for district heating, and the heterogeneity in demand responses to changing district heating prices.
- Determinants of district heating consumption: household income, household size, living area, heating allowance, heating degree days, living outside the Capital Region of Denmark, living in an old dwelling.
- The choice of the estimation method significantly affects price elasticity estimates. Static models: the short-run price elasticity ranges from -0.913 to -0.797. Dynamic models: the short-run price elasticity ranges from -0.545 to -0.367, while the long-run price elasticity ranges from -0.72 to -0.45.
- Based on our preferred method – the Blundell-Bond two-step system GMM, we find that the short-run price elasticity is -0.489, while the long-run price elasticity is -0.66.
- Price elasticities vary as a function of income, consumption, dwelling tenure, gender, household type, dwelling age. For example, households with lower income and higher consumption levels are more responsive to price increases.
- An increase in the carbon tax can be effecting in reducing district heating demand and encourage residential energy efficiency investments. However, a single policy instrument can rarely deliver significant energy demand reductions (and address environmental externalities) while maintaining high welfare standards if applied in isolation.

Thank you for your kind attention

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