Universität St.Gallen

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May 2018 Discussion Paper no. 2018-05

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Department of Economics

University of St.Gallen

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Publisher:	School of Economics and Political Science Department of Economics University of St.Gallen Müller-Friedberg-Strasse 6/8 CH-9000 St. Gallen Phone +41 71 224 23 07
Electronic Publication:	http://www.seps.unisg.ch

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[1] We thank participants at seminars in CREST, University of Gothenburg, University of Mannheim, IFN (Stockholm), Swedish Competition Authority (Stockholm), Swedish Energy Economics Conference (Lulea), EEA (Geneva) and EC[2] (Edinburgh) for useful comments. Special thanks to Pierre Fleckinger for many insightful discussions. Petyo Bonev and Magnus Söderberg acknowledge the generous financial support from the Swedish Competition Authority, grant number 372/2016.

Abstract

This is the first study that uses a natural experiment to test the Regulatory Threat Hypothesis. We use a unique novel dataset on unregulated Swedish local district heating monopolists and a new measure of threat - customer complaints. Our results support the Regulatory Threat Hypothesis: firms reduce prices when they feel threatened by price regulation. We also find evidence that (otherwise unrelated) monopolists homogenize locally prices to reduce complaints and thus to reduce threat of regulation. This mechanism is related to Yardstick competition and to behavioral theories of fair pricing.

Keywords

Regulatory Threat, Monopoly, Price Setting, Spatial Interaction, Natural Experiment

JEL Classification

L11, L12

1 Introduction

We empirically study whether the threat of stricter regulation disciplines the pricing behaviour of firms. This hypothesis, referred to as the Regulatory Threat Hypothesis in the literature,[1] has been theoretically derived by Glazer and McMillan (1992) with a model that describes the behavior of an unregulated monopolist that faces the risk of regulation. They show that the pricing decision resembles limit pricing to deter entry, except that its goal is to deter regulation.[2]

The RTH has been difficult to test statistically.[3] The analyst first needs to observe the threat, which corresponds to expectations formed by a firm on the likelihood of future policy reforms. The usual strategy consists of measuring media coverage of policy debate and proposals or the occurrence of public discussion on the issues at stake. This is however not sufficient to identify firms' behavior as these variables typically do not vary across firms. In order to obtain a firm-level variations, analysts then interact these generic variables with firm characteristics that influence either the probability of regulation through "political and public visibility" (e.g. size of the firm), see e.g. Stango (2003), or the expected financial loss of the firm in the case of regulation (such as weighted average patent duration), Ellison and Wolfram (2006). Such indicators provide an indirect measure of firm-specific threat levels at best, and the data patterns are compatible with alternative mechanisms, such as reputation effects and entry deterrence.[4]

A second empirical challenge is that the probability of regulation and the level of prices are jointly determined. Increases in threat levels lead firms to reduce prices, but

[1] See e.g. Erfle et al. (1989).

[2] Related analyses have been developed to explain the voluntary adoption of product quality standards Lutz et al. (1998), corporate environmentalism Maxwell et al. (2000), preemption to anti-trust enforcement Block and Feinstein (1986).

[3] Empirical studies on the RTH are for example those of Erfle et al. (1989), Erfle and McMillan (1990), Wolfram (1999), Maxwell et al. (2000), Boyer (2000), Acutt et al. (2001), Stango (2003), Antweiler (2003) and Ellison and Wolfram (2006).

[4] E.g. Stango (2003) acknowledges that his empirical evidence that firm visibility leads to a higher price cut in a period of threat is also compatible with behaviour of firms due to intensified competition with new entrants.

price changes also influence regulators' propensity to regulate. This potentially induces endogeneity in the measure of threat. Market-level natural experiments are typically hard to find, a problem that is related to the empirical problems in macroeconomics, see Fuchs-Schuendeln and Hassan (2015) for a discussion. Researchers have therefore either relied on simple OLS (see e.g. Boyer (2000)), or strong parametric assumptions on the error term (Ellison and Wolfram (2006)), or on non-experimental instrumental variables (IV) (Erfle and McMillan (1990) and Antweiler (2003)). Although not uncommon in empirical industrial organization, such identification strategies have been subject to an increased criticism in recent years for their lack of credibility, see for example Angrist and Pischke (2010) and Gibbons and Overman (2012).

In this paper, we use a novel dataset to evaluate the effect of regulatory threat on prices in the context of the Swedish District Heating (DH) market. This market has several salient characteristics that make it suitable for testing the RTH. It consists of many (unrelated) local monopolists and the price is not regulated. The relevance of introducing a regulation has been subject to a continuous political debate since 2005. The peak of these discussions was the passing of the District Heating Act in 2008. This law does not include a formal price regulation. Instead, it enabled consumers to complain about DH prices to the so-called Swedish District Heating Board (DHB)). Upon receiving complaints, the Board must organize a negotiation between the complaining customer and the concerned DH firm, without any power to impose sanctions. Thus, the Board only makes the pricing strategy of particular firms more transparent. We give more details on the institutional context in Section 2.1.

We contribute to the empirical literature on RTH in several ways. First, we use a measure that more closely captures firm-specific regulatory threat, namely the count of customer complaints made to the DHB about individual firms' prices. The DHB owns its very existence to the public debate over the relevance of regulation and is expected to create informal pressures on firms. This gives our study the advantage that the measured effects are more clearly attributed to threat, implying that it is easier to rule out alternative explanations.

Second, to the best of our knowledge, this is the first paper that uses a natural experiment for the evaluation of the RTH. We use random variation in unforeseen technological failures of district heating as an instrument for customer complaints. These failures increase the propensity to complain, but due to the unique (institutional) setup of the Swedish DH market, they have no direct impact on the price. In particular, the exclusion restriction on the supply side is motivated by a regulatory norm, which requires firms to separately report service failures that have no predictive power for future supply. On the demand side, our exclusion restriction follows from the specifics of Swedish DH as a consumption good: customers of DH firms are locked in to their service provider. These two features effectively prevent the technological failures from having a direct impact on the price. These exclusion restrictions and the quasi-random nature qualify unforeseen failures as a suitable instrument for the endogenous threat measure. Our strategy is similar in spirit to the natural experiment used in Bressoux et al. (2009), who utilize random administrative mistakes to instrument for the endogenous assignment of teachers to schools in France. In both cases, the source of exogenous variation is unforeseen random failures. We find empirical support for the RTH. The estimates of the effect of complaints on prices are negative and significant.

A third contribution of our paper is to shed light on how firms strategically interact in order to reduce the threat of regulation. We provide evidence that firms reduce the difference between their price and those observed in neighboring municipalities. We refer to this hypothesis as the Strategic Interaction Hypothesis (SIH). The underlying theory is that this strategy helps to convince customers that the local price is “fair”, thereby reducing complaints. This mechanism draws on theoretical and empirical findings of the behavioral economic literature. A major result in this literature is that consumers rely on standards to judge whether a price is “fair” and fairness standards influence their behavior., see e.g. Kahneman et al. (1986) and Rotemberg (2011). The production cost provides an obvious standard, but consumers cannot easily infer its value in industries with complex production processes. In such cases, they use other references, in particular, the prices set by firms producing a similar type of goods or services, Kahneman et al. (1986), Rotemberg (2005) and Rotemberg (2011). If the price is judged as unfair, consumers suffer an emotional cost and might get angry.

In cases when customers are locked in to the service (as in the context of the Swedish DH market), they cannot but complain to express their disagreement with a price policy. We provide empirical evidence that consumers complain when they observe high positive differences between the local DH price and the prices charged in neighboring markets.

A major empirical challenge in testing the SIH is that common unobserved factors of demand and supply may also generate a spurious spatial spillover effect. In order to identify the causal effect of neighboring prices on local prices, we use a natural experiment triggered by a political intervention. In 2008, the Swedish government introduced a subsidy which provided residential property owners with incentives to increase the energy efficiency in buildings. This subsidy induced a permanent change in the characteristics of DH customers, which shifted demand curves. We use local variations of the induced demand shift as an instrument for the endogenous prices. The policy was not anticipated by firms and customers as there was no political or public debate prior to its introduction. The exclusion restriction is motivated by the unique setup of the DH utility network in Sweden: markets are legally independent and they do not share profits or customers. Our identification strategy is related to the one used by Lyytikäinen (2012), who uses local variation in tax increases induced by a national policy reform to identify the spillover effect of local tax levels in a tax competition setting. Our strategy is also related in spirit to the natural experiments used to test the Permanent Income Hypothesis, as the majority of these settings rely on an unanticipated income shift, see Fuchs-Schuendeln and Hassan (2015) for a detailed overview and discussion.

We find strong support for the SIH. The estimate of the spatial spillover effect is positive and significant. The result is robust to a variety of specifications, including alternative estimation methods such as Maximum Likelihood and Indirect Inference. Furthermore, we pay particular attention to separating the threat mechanism from competing mechanisms. We utilize intertemporal and cross-market variation of the overall level of regulatory threat to show that when the level of threat decreases, the spatial price spillovers disappear.

The SIH provides an additional mechanism for how firms may react to avoid stricter regulation. Its main difference to the RTH is that it features a joint reaction of firms. The majority of empirical papers on regulatory threat has ignored potential interactions of firms due to the empirical complexity that arises in such cases.[5] Our study design is particularly suitable for the analysis of firms interactions, as the independence of the markets allows to isolate the threat effect from other mechanisms.

Our empirical findings lead to several policy implications. The disciplining effect of complaints on prices does not only support the RTH, but also provides an important insight on how to construct an institutionalized mechanism for threat of regulation. This insight goes beyond the range of policy implications of related papers: the majority of empirical papers do not elaborate on how to create sustainable threat. Increased threat is regarded as a temporary consequence of a current political debate. Therefore, the time window of threat is necessarily short, see Acutt et al. (2001), Driffield and Ioannidis (2000), Elliott et al. (2016), Elliott and Wei (2010), Elliott et al. (2010), Ellison and Wolfram (2006), Stango (2003) and Wolfram (1999). Our study, on the contrary, deals with a period of observation of over 6 years (2008 - 2014), with the implication that customer complaints can be a sustainable mechanism for maintaining threat over time.

[5] Ellison and Wolfram (2006) and Elliott et al. (2010) are the two papers that explicitly consider firm interaction in the context of threat, with the specification of Elliott et al. (2010) closest to ours. Elliott et al. (2010), however, estimate the spatial spillover effects in a simple OLS framework, ignoring potential endogenity. Further papers that discuss but do not explicitly tackle firm interactions under threat are those of Antweiler (2003) and Brunekreeft (2004).

2 Institutional setup and data

2.1 Institutional setup

As of 2014, there is a DH firm in 262 of the 290 Swedish municipalities (one firm per municipality). All these utilities are vertically integrated, i.e. production and distribution is owned by the same firm. With the exception of two large firms (E.ON and Fortum) and a few smaller collaborators that own networks in several municipalities (and for which reason they are excluded from the empirical analysis), each firm/market is economically and legally independent from all other firms/markets.[6] DH technology is only viable in densely populated urban areas and the high fixed distribution costs imply that each utility is a local natural monopoly.[7]

Customers in cities typically have only two possible sources of heat to choose from. The first is DH and the second is electricity-based technologies (primarily in the form of heat pumps) see the RES Report for further details about the Swedish heating market.[8] Once the customer has connected, DH is the cheaper source of heat compared to electricity with a ratio of variable costs around 0.5 (EMI, 2012)).[9] Due to the geographical restriction of DH and the high switching costs, DH customers are locked in to their providers. Furthermore, the lock-in effect and the essential nature of heating lead to price elasticity of demand close to zero, (Braennlund et al., 2007; Leth-Petersen and Togeby, 2001).

The DH prices are set independently by each firm and since 1996 prices are not subject to any periodic sector-specific review by a regulatory agency.[10] This is in stark contrast to how electricity prices are set: the retail price is determined on a competi-

[6]In particular, DH firms do not share management, customers and profits.

[7]A further implication is that a customer can only purchase DH from the firm in the city where she resides.

[8]Natural gas plays a negligible role in Sweden and oil was practically phased out during the 1980s and 1990s

[9]There is a one-time connection fee that is paid at the time when the dwelling is connected to the network. This fee is high and can amount to ten times the total annual consumption cost.

[10]In addition, the market opened for private investors in 1996.

tive spot market and the transportation prices (transmission and local distribution) are regulated by the Swedish Energy Markets Inspectorate through ex post revenue caps.

At the end of 2005, a national debate started with calls for stricter regulation of DH prices. Customers complained about high DH prices which led the government to discuss the need to implement stricter regulation (SOU 2005a, b). The regulatory debate culminated with the implementation of the District Heating Act (2008:263) in 2008. The most important consequence of the Act was the establishment of a national complaint board (the Swedish District Heating Board, DHB). Since July 2008 a consumer who is dissatisfied about its DH price can file a complaint to the DHB. If the complaint is considered well grounded, the committee launches a negotiation process between the consumer and the utility and it provides expert opinions about how a competitive DH price should be determined in the situation that the customer complained about. The DH firm can accept or reject the board's suggestion without any direct consequences. Therefore, the District Heating Act provides consumers with no real additional rights, but it publicly exposes consumer dissatisfaction. One of the main hypotheses of this paper is that the DHB generates in this way threat of regulation that leads firms to adjust their prices.

2.2 Data

Our dataset contains annual information on each local DH market. Information about prices was gathered from the Nils Holgersson annual price survey (NHS), which reports municipal specific list prices for a representative customer.[11] DH firms in Sweden review and adjust prices once a year and they normally implement the new prices on the 1st of January. To give customers some notice period, they review their prices between

[11]The prices are available at http://www.nilsholgersson.nu. This annual survey is run by several of the largest organizations with interest in the Swedish property markets, specifically the Swedish Union of Tenants, HSB Riksfoerbund (Sweden's largest housing cooperation), Riksbyggen (an organization owned by the building unions, local housing associations and by other national co-operative associations), SABO (the Swedish Association of Public Housing) and the Swedish Property Federation.

September and November.

Information on customer price complaints was collected directly from the DHB.[12] Additional demand and supply characteristics were added from other sources. On the supply side, we have information on the firm specific shares of different fuel types used to produce heat. The types and amounts of fuel used affect firms' cost levels. This information was collected from the Energy Markets Inspectorate and directly from the DH firms. We also observe labor cost for the period 2008-2014. On the demand side, our dataset contains municipal-specific information on the average income, the share of population above the age of 65, the total number of inhabitants, the share of detached dwellings (i.e. single family houses).[13, 14]

Table 5 in appendix A contains descriptive statistics on the subsample used to test the RTH. Due to restricted availability of the data on the instrument, we only use the periods 2010-2013 for these regressions.[15] The last variable in this table, "Unanticipated disruptions", is explained in section 3. In table 6 in appendix A, we show descriptive statistics for the period 2008-2009. Data from these periods are used to test the SIH. The table contains descriptive statistics for the local price levels in 2008 and 2009, as well as for the relative changes of all variables in that time period. The relative change variable is defined as (Variable 2009 - Variable 2008)/Variable 2008. The relative changes of the observed covariates (other than prices) between 2008 and 2009 have only little variation across units. This finding is important for the interpretation of our main results in section 4. The relative price change, on the the other hand, exhibits substantial variation with largest price change being 28%, and the lowest being negative. Some of the firms even reduced their prices. Further, the spatial correlation between the price in a market and

[12] See http://www.energimyndigheten.se.

[13] These variables are collected from Statistics Sweden and the municipalities directly.

[14] Additional covariates such as the electricity tax (a measure of the price of the substitute) and weather (number of heating degree days, amount of precipitation) were also gathered. Since they have no (electricity tax) or only very limited (weather) cross-sectional variation, including them into the analysis made no difference. Results available upon request.

[15] See section 3 for details.

the price in the closest neighboring market is 0.368 in 2008 and 0.373 in 2009.

We exclude observations when we either do not observe the price or the instrument. We also exclude larger firms that own utilities in several markets. Section A.2 in the online appendix presents evidence, that this exclusion does not pose a threat to the internal validity of the main results.

Tables 7 and 8 in appendix A present descriptive statistics for the periods 2009-2014 and 2003-2004. These periods are used for the regressions in sections D (appendix) and 5, respectively. The reasons for the choice of the particular sub-period/sub-sample are explained in detail in the corresponding section.

3 Testing the Regulatory Threat Hypothesis

3.1 Identification strategy

The most straightforward way to formulate the RTH is to assume the following relationship:

$$p_{it} = \phi(C_{it}, V_{it}) \tag{1}$$

where p_{it} is the price charged by the local monopolist in market i at time t, C_{it} is the number of complaints filed by consumers in market i, and V_{it}, a vector of observed and unobserved factors that influence the price. ϕ is a function that relates these variables. The RTH then requires that:

$$\frac{\partial \phi}{\partial C_{it}} < 0 \tag{2}$$

Testing (1) in a regression context with C_{it} as an independent variable is potentially hampered by the endogeneity of C_{it}. Price and complaints are in a reverse causality relation, so that C_{it} is correlated with the unobserved components of V_{it}.

To instrument for C_{it}, we use a natural experiment induced by unanticipated technical failures. DH services occasionally exhibit temporary disruptions during which no heat is provided to customers. A unique feature of the Swedish DH institutional context is that firms are obliged to report these service disruptions to the Swedish Energy Regulator, and separate reporting is provided for “anticipated” and “unanticipated” disruptions. Anticipated disruptions are disruptions that are known in advance, either because they are triggered intentionally by the DH provider (e.g. service shutdown for maintenance), or because technical failures have a repetitive character (e.g. due to depreciation of materials and components). Therefore, the amount of anticipated disruptions can be predicted based on experience. An example of this category would be an annual trend in the average number of days of disruption due to mechanical breakdowns in specific technical components. DH firms typically announce the expected duration (as well as point in time) of anticipated disruptions on their homepage and sometimes also in the local media. Hence, customers can adapt in advance to these.

In contrast, “unanticipated” disruptions are irregular and unpredictable. They result from unforeseen technological breakdowns. Examples are leaks in the distribution network, or unexpected breaks of valves and other technical components. Their frequency, duration and occurrence are not known in advance, neither by the customers nor by the firms. Moreover, these disruptions are unanticipated in the sense that their amount in one period has no predictive power for the amount in the subsequent periods. As a consequence, unanticipated disruptions in one period have no influence on the supply expectations of a firm for the next period. We denote the number of unanticipated service disruptions by D_{it}. Intuitively, D_{it} in each period can be viewed as a noise in the total amount of service disruptions, and the process $(D_{it})_{t=1996,1997,...}$ can be viewed as the increments of a random walk stochastic process.

We use unanticipated service disruptions D_{it} as an instrument for C_{it}. We observe D_{it} for the period 2011-2013, see table 5 in section A for a summary of its empirical distribution. Due to the importance of heating in a cold country like Sweden, disruptions in the service can create substantial disutility among customers. It is plausible that angry customers are more likely to complain as they do when prices increase.

Moreover, the random, unanticipated nature of D_{it} qualifies them as a natural experiment, which we now support with a detailed discussion. Our discussion revolves around the two possible channels of invalidation of an instrument: a direct effect on the price (violation of the exclusion restriction), and endogeneity through unobserved confounding factors.

The validity of the exclusion restriction

A violation of the exclusion restriction on the demand side would occur if D_{it} has a direct impact on the price through a shift in the demand of the firm. Such a shift can be caused either by already connected (i.e. actual) customers or by potential customers. For already connected customers, the demand for DH is inelastic with respect to technical disruptions (at least when the number of disruptions are below a certain number). The reasons for this inelasticity are identical to the reasons for the inelasticity with respect to price changes, described in section 2.1. For potential customers, the exclusion restriction can be motivated mainly by the frequency of disruptions. Unanticipated service disruptions are extremely rare events. Disruption in the electricity service is much more common because the electricity network is more sensitive to severe weather occurrences (wind and wet snow that break overhead lines). Therefore, it is unlikely that customers will decide not to connect to DH because of unanticipated disruptions.[16]

The exclusion restriction would be violated through the supply side if unanticipated service disruptions directly shift the supply curve of the firm, i.e. the amount of DH the firm is willing to supply at a given price. Such a direct effect can be safely precluded due to two main arguments. First, unanticipated service disruptions in one period have no predictive power for unanticipated service disruptions in the next period. Thus, the firm

[16]The only severe DH disruption that has happened in Sweden was in March 2016, when 2500 cubic meters of hot water leaked out in a small town in the south of Sweden. This caused the death of one person and it reached the national news. We acknowledge, that events that attract so much attention might affect some property owners when they invest in heating technology. This event, however, is outside our sample period.

cannot use the cost resulting from such events in one period to build an expectation for the cost in the next period (and hence, to adjust the price). Anticipated cost changes are based solely on anticipated service disruptions A_{it}. Second, as discussed above, D_{it} are rare events and their contribution to total cost is negligible.

Confounding factors

Since D_{it} result from random technical failures, they are not related to unobserved factors of demand. We therefore focus on possible confounding factors on the supply side. In principle, it cannot be excluded that D_{it} are related to technology type and management of the facility. In the short period of observation (3 years) however, those factors can be assumed fixed for each firm. In our main results below, we account for firm- and time-specific variation by including firm fixed effects and year dummies.

In addition, we back up our analysis with a regression of D_{it} on observed covariates. The estimated coefficients have no causal interpretation, but provide indirect evidence of whether D_{it} is related to unobserved confounding factors. The results are shown in table 10 in section B in the online appendix. None of the estimates is significant, which provides evidence that D_{it} is not related to unobserved confounding factors.

3.2 Empirical results

We estimate the model

$$p_{it+1} = \beta_0 + \gamma C_{it} + X_{it}\beta + \sum_{l=1}^{T-1} \delta_l T_l + \theta_i + \varepsilon_{it}. \tag{3}$$

where X_{it} is a $1 \times k$-dimensional random vector of observed covariates, T_l are time dummies with $T_l = 1$ if $l = t$ and 0 otherwise, θ_i are municipality fixed effects, γ, β_0, $\beta = (\beta_1, \ldots, \beta_k)'$ and $\delta_1, \ldots, \delta_{T-1}$ are unknown coefficients,[17] and ε_{it} is the time-varying idiosyncratic error of the regression model. The main parameter of interest is γ. It can

[17] We denote the transpose of a matrix or a vector a by a'.

Table 1: Empirical results, testing the RTH.

	OLS FE	IV FE		
	(1)	(2)	(3)	(4)
Complaints	-0.015	-5.57**	-5.55**	-5.88**
	(0.18)	(3.29)	(3.32)	(3.44)
Population	-1.82			-1.58
	(1.78)			(2.97)
Age > 65	295.24			411.3
	(445.2)			(763.2)
Labour Cost	0.009***			0.01**
	(0.003)			(0.006)
Year dummies	Yes	Yes	Yes	Yes
Fixed effects	Yes	Yes	Yes	Yes
Num of obs.	927	927	927	927
I-Stage F-stat.		4.79	4.74	4.62

Note: Specification (1) estimated using OLS. Specifications (2)-(4) estimated using IV. Specification (2) estimated under the assumption of i.i.d homoskedastic errors, specifications (3) and (4) under HAC-robust errors. * denotes $p < 0.1$, ** denotes $p < 0.05$, *** denotes $p < 0.01$. One-sided test p-values for the estimate of Complaints.

be interpreted as the threat effect that complaints in market i induce on the DH price in that same market. The RTH predicts a negative γ (in line with (2)). Note that prices for for period $t+1$ are set by the firms at the end of period t (timing is discussed in the next section in detail), which explains the lagged index on the r.h.s. of (3)

The results are shown in Table 1. Each of the specifications (1)-(4) corresponds to a different set of underlying assumptions. Specification (1) assumes exogeneity of C_{it}, and the estimates are obtained with an OLS fixed effects (FE) estimator. The estimate $\hat{\gamma}_{OLS}$ is negative but insignificant. This coefficient is also of a very small magnitude. According to this result, 100 additional complaints would lead to a 2 SEK decrease of the price per unit DH, which is approximately 0.0002% of the average price in 2011. Given how rare complaints are – the third quartile of their empirical distribution is equal to 0 – the economic interpretation of the estimate is that complaints create no real pressure on firms to reduce prices.

Estimates in specifications (2)-(4) are obtained with a TSLS FE estimator and D_{it} as an instrument for C_{it}. Specification (2) assumes homoskedastic i.i.d. disturbances, whereas (3) and (4) produce standard errors that are robust to heteroskedasticity and autocorrelation (HAC). Furthermore, while specifications (2) and (3) include only C_{it} as a covariate, specification (4) includes observed covariates.[18]

All three IV specifications produce very similar estimates for γ and they are all negative and statistically significant at the 5% level. As an example, the estimate in (2) is equal to -5.57, which implies that 10 additional complaints lead to a price decrease of 55 SEK, or a 6.5% reduction of the average price in 2011. Hence IV estimates are approximately 350 times higher in magnitude than the corresponding OLS estimate. A Durbin-Wu-Hausman test rejects the exogeneity of C_{it} (p-value = 0.0051).[19] The positive bias is in line with economic intuition. In particular, since prices and complaints are in a reverse causality relation, factors that shift prices up also increase complaints (through the increase in prices).

According to the estimates in (4), out of all additional observed covariates, only labor has a significant effect but with a very small magnitude. This result is not surprising since both the number of households and the share of population above 65 are variables that are rather stable over time. As a consequence, little variation is left to estimate their impact on prices.

Note that the estimates of all 3 IV specifications are significant. The first-stage results of the three IV specifications are displayed (in this order) in table 11 in section B of the online appendix. The estimated coefficients of D_{it} are positive and significant in all three specifications. This is in line with the intuition that more service disruptions lead to more complaints through decreased tolerance.

Note that the instrument appears to be weak (the F statistic of the first stage is

[18] Thus, while one advantage of specification (4) is to give a more detailed picture, the advantage of specifications (2) and (3) is that they are not prone to omitted variable bias via additional covariates.

[19] We implement the version of the test that is robust to HAC errors, see e.g. Hayashi (2000), p. 233-234.

between 4.62 and 4.79). This, however, is not of concern for our estimates, since all 3 specifications are just-identified (because we only have one endogenous regressor and one instrument). As a result, the GMM-IV, TSLS and the LIML estimators are equivalent, see for instance p.189 in Wooldridge (2010), or chapter 8.6 in Hayashi (2000). In addition, in the just-identified case, the GMM-IV estimator has the appealing property to be approximately unbiased and to achieve close to perfect nominal coverage (see e.g. Angrist and Pischke (2009b) and Angrist and Pischke (2009a)). The only issue related to weak instruments in the just-identified case remains the wide confidence bounds. Despite this problem, our estimates are significant.

All in all, the results of this section support the RTH. Despite the lack of any legal authorities in the price setting process, the DHB creates incentives for self-regulation through visibility of complaints.

4 Testing the Strategic Interaction Hypothesis

4.1 Theoretical framework

The SIH is based on the arguments evoked in introduction. As the customer does not know the marginal cost of DH, she uses prices that she observes in neighboring markets as reference pricesKahneman et al. (1986), Di Tella and Dubra (2014) and Rotemberg (2011). Since the cost of switching from DH to any other heating technology is excessively high, a customers who is dissatisfied with the price level can only complain. These considerations translate into the following assumptions:

$$C_{it} = \psi(p_{it}, p_{-it}, A_{it}) \quad \text{with} \quad \partial\psi/\partial p_{it} > 0 \quad \text{and} \quad \partial\psi/\partial p_{-it} < 0. \qquad (4)$$

Here, p_{-it} is the (weighted) average of prices in markets that are ”close” to market i, $p_{-it} = \sum_{j \neq i} w_{ij} p_j$, where w_{ij} are non-negative spatial weights that sum up to 1. If market j is considered as close to market i, then w_{ij} is positive. As an example, in the base specification, we consider markets to be close to market i if they share a border, see section 4.3. In section C in the appendix, we explore alternative definitions of closeness. A_{it} is a vector of factors influencing the propensity to complain and ψ is a function that relates the different variables. According to relationship (4), the higher the price in i, the higher the level of dissatisfaction, which manifests itself in the number of complaints. In contrast, higher surrounding prices reduce the number of complaints. The intuition behind is that big differences to reference prices lead the customer to doubt on the fairness of the own price level.

The assumption that consumers only look at geographically close markets is common in the literature, see Lyytikäinen (2012) and LeSage and Kelley Pace (2009). In the setting of the Swedish DH market, it can be motivated by the existence of a positive correlation between search costs and distance, or by similarities across close markets (which increase the information content of neighboring prices), see appendix C.1 for an extensive discussion.

Plugging (4) in (1) yields

$$p_{it} = \phi(\psi(p_{it}, p_{-it}, X_{it}), A_{it})$$

This equation defines an implicit relationship between p_{it} and p_{-it}. Assuming an exogenous shock on p_{-it}, we can differentiate this expression with respect to p_{-it}, leading to

$$\frac{\partial p_{it}}{\partial p_{-it}} \times \left[1 - \frac{\partial \phi}{\partial C_{it}} \frac{\partial \psi}{\partial p_{it}}\right] = \frac{\partial \phi}{\partial C_{it}} \frac{\partial \psi}{\partial p_{-it}}$$

Given the assumptions made above on the sign of different derivatives of ϕ and ψ, we immediately deduce the SIH:

$$\partial p_i / \partial p_{-i} > 0. \tag{5}$$

The intuition behind (5) is that an exogenous increase of p_{-i} decreases the complaints C_i, which gives a possibility for firm i to increase profits without triggering regulation.

Assumption (4) and hypothesis (5) are empirically testable. In the remainder of the paper, we focus on (5). A test of (4) is presented in appendix D.

4.2 Identification strategy

A major challenge for identifying (5) is that the spatial lag p_{-i} is potentially endogenous due to the simultaneity of the price setting. To instrument for p_{-i}, we utilize a natural experiment triggered by a policy shock. On December the 5th, 2008, the Swedish government announced that households in detached houses will be subject to an optional subsidy of 50000 SEK (equivalent to about 4800 € in December 2008) to increase the energy efficiency of their homes. The subsidy could be used for any type of measures that improve the energy efficiency of the dwelling, including the connection to district heating.

To construct our instrument, we exploit the time structure of this policy, which is depicted in figure 1. The dashed vertical line denotes the date of the announcement of the policy 5th December 2008. The official start was only 4 days later: the subsidy could be claimed from the 9th of December. The last possible day for claiming the subsidy was 30th of June 2009, or about 7 months after its implementation. Prior to the official announcement of the subsidy, there was limited debate about it. The proposal about the subsidy was first debated in the Swedish national parliament on the 8th of October 2008, only two months before its announcement and implementation.[20] Moreover, DH prices are adjusted only once per year. As a general industry rule, DH firms adjust prices for year t during September-November (and particularly in October) of year $t-1$.[21]

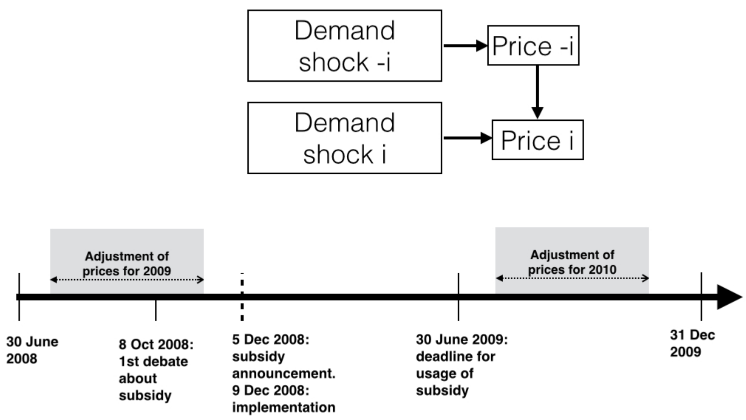
[20] The link to the official report of the government about this debate is https://www.riksdagen.se/sv/Dokument-Lagar/Forslag/Motioner/Inforande-av-ROT-avdrag_GW02Sk379/?text=true .

[21] See http://www.sevab.com/Privat/Fjarrvarme/Priser/ for more information and examples (in Swedish).

Thus, the adjustments for 2009 took place before the introduction of the subsidy, and the adjustments for 2010 took place after the last day the subsidy could be claimed. The two adjustment periods are depicted with shaded rectangles in figure 1.

The motivation of our instrumental strategy is that this subsidy made connecting to DH cheaper, which is likely to have attract new consumers. This change in the customers stock was likely to have a permanent character: after connecting to DH, consumers are locked-in due to the high cost of initial investment and the comparatively high price of the substitute (electricity). As a result, the subsidy is likely to have induced a change in the 2010 prices. Therefore, local variation of this change in the customer stock can be used as an instrument for the endogenous prices p_{-i}. In particular, as depicted in figure 1, a shock in the demand stock in markets $-i$, neighboring with market i, is likely to have changed the price in markets $-i$, but it had no direct effect on the price in market i. The logic behind the exclusion restriction is discussed in detail below.

Figure 1: Ttiming and causal structure of the change in customer stock.



Unfortunately, we do not observe the size of the change in the stock of customers, as we have no information on individual households' decisions to claim the subsidy. Instead, we use a proxy variable. In particular, define

$$Z_i := \frac{\text{Number of detached households in municipality i}}{\text{Total number of households in municipality i}}. \tag{6}$$

In a first-difference regression, we use Z_{-i2009} as an instrument for the endogenous price difference $p_{-i2009} - p_{-i2008}$, where Z_{-it} is defined analogously to the definition of p_{-it} and equal to $\sum_{j \neq i} w_{ij} Z_{jt}$. In particular, the spatial weights are identical to those in the definition of p_{-it}. Thus, implicitly, each change of the demand stock in a neighboring market instruments for the price in that market. The interpretation of Z_{-it} is as follows. The nominator in (6) measures the maximum number of households that would have been eligible for the subsidy if no detached households had yet connected to DH. This is a (fictive) upper bound for the number of new customers of a DH firm due to the subsidy. The denominator in (6) measures the total size of the demand of the DH firm in the fictive case where all households are customers. Thus, the variable Z_{it} provides a measure of the maximum potential change in customer stock in municipality i due to the subsidy. It is thus similar to an Intention-to-Treat variable which results from the treatment assignment in a randomized experiment, see Heckman et al. (1999). As we document in online appendix C.2.1, Z_{it} exhibits rich variation over its support $[0, 1]$.

We now discuss in detail the properties of $Z_{-i,t}$ that qualify it as a valid instrument.

Exclusion restriction. Z_{-it} is a valid exclusion restriction since it has no direct effect on the price in market i due to the economic and legal independence of the markets as discussed in section 2.1.[22]

No anticipation. Neither customers nor DH firms anticipated the policy shock. The time span from the first debate on the 8th of October to the actual decision to introduce the subsidy was only 8 weeks. Moreover, the discussion on the 8th of October left room for uncertainty, as it had no clear outcome/announcement regarding precise

[22]The exclusion restriction is depicted on figure 1 as the lack of a direct link between Z_{-it} and p_{it}.

content and timeline.[23] In addition, the time span between the official decision on the 5th of December and the actual implementation was only 3 days. No anticipation of the reform is an important characteristics, as it precludes forward looking unobserved behavior that can potentially influence the prices.[24]

The substitute. We document in appendix C.2.2 that the price of the only substitute (electricity) had no time and regional variation for the period of consideration. As a result, there was no unobserved variation of competition intensity that is potentially related to the change in customer stock Z_{-it}.

No correlation between Z_{-it} and unobserved factors of the price in market i. In a manner similar to section 3.1, we regress the instrument Z_{-i2009} on observed covariates in market i. The results are presented in table 12 in appendix C.2.3. Although the estimated effect of number of households is significant, the magnitude of the coefficient is economically irrelevant. All other observed covariates have insignificant estimated coefficients. Thus, this regression presents indirect evidence that Z_{-i2009} and the unobserved factors of the price in market i are not correlated. This result is reinforced by the fact, that Z_{i2009} itself is not significantly spatially correlated. The correlation of Z_{-i2009} and Z_{i2009} amounts to 0.13. The p-value of the Moran's I test is 0.11, so the test fails to reject the null hypothesis of no spatial correlation at the 10% level. In addition, a graphical inspection of the spatial distribution of Z_{i2009} reveals no visible patterns of dependence, see figure 3 in appendix C.2.1.

These regression results also imply that the instrument is not related to (changes in) unobserved variable costs. In particular, labor costs and fuel costs are the main variable costs of district heating, amounting to more than 90% of the total variable cost.[25] While

[23]In particular, it was not clear which components the subsidy could be used for.

[24]As an example of such behavior, if customers anticipate the subsidy (and in particular, its date of implementation and content), they might postpone major energy efficiency investments for the period after the subsidy is introduced. Such a behavior would result in a downward shift of the DH demand in 2008 and hence in a possible adjustment of prices already in 2009. Another example is if firms adjust their 2009 prices in anticipation of a future shift in the demand.

[25]See e.g. Difs and Trygg (2009) and Sjödin and Henning (2004) for case studies of calculating DH

labor cost is observed directly and appears to be uncorrelated with Z_{-i2009}, the fuel cost has virtually no local variation. In particular, Sweden is divided into 3 large “fuel regions”. Within each of those regions, markets are exposed to the same price for most fuels, including biofuel (which is the major fuel type used by DH firms). Thus, variation in fuel cost is not related to local market characteristics.[26]

4.3 Empirical specification and results

We estimate the model

$$p_{it+1} = \beta_0 + \rho \sum_{j \neq i} w_{ij} p_{jt+1} + X_{it}\beta + \sum_{l=1}^{T-1} \delta_l T_l + \theta_i + \varepsilon_{it}, \tag{7}$$

where the time lag of observed and unobserved covariates reflects the timing of price policies. The main parameter of interest is ρ. It can be interpreted as the first derivative of p_{it} with respect to the average of neighboring prices p_{-it}, $\rho = \partial p_{it}/\partial p_{-it}$, with $p_{-it} = \sum_{j \neq i} w_{ij} p_{jt}$. It gives the strength of the spatial spillover of neighboring prices on the price in market i. To utilize the time structure of the policy reform described in the last section, we take the first-difference of two consecutive periods and estimate

$$p_{i2010} - p_{i2009} = \beta_0 + \rho \sum_{j \neq i} w_{ij}(p_{j2010} - p_{j2009}) + (X_{i2009} - X_{i2008})\beta + (\varepsilon_{i2009} - \varepsilon_{i2008}). \tag{8}$$

Spatial lags of covariates are not included due to the economic and legal independence of the markets. Table 2 presents the results of three different specifications. In all three

marginal costs and the relation between marginal cost and price.

[26]See the website of the Forest Statistics Yearbook, where prices for most fuel types are reported: http://www.skogsstyrelsen.se/en/AUTHORITY/Statistics/Statistical-Yearbook-/Statistical-Yearbooks-of-Forestry/

specifications, the weights are chosen according to the rule

$$w_{i,j} = \begin{cases} 1/bn_i & \text{if municipality } j \text{ shares a border with municipality } i \\ 0 & \text{otherwise,} \end{cases} \tag{9}$$

where bn_i is the number of bordering neighbors of municipality i.[27] This specification implies that all firms from bordering municipalities have an equal weight. It is a common choice of spatial weights in the literature, see LeSage and Kelley Pace (2009). In section C.4 in the appendix, we present results obtained under a variety of alternative weighting schemes. Furthermore, the results of specifications (1)-(3) are obtained with a GMM estimator with $\sum_{j \neq i} w_{ij} Z_{j2009}$ as an instrument for the endogenous $\sum_{j \neq i} w_{ij}(p_{j2010} - p_{j2009})$. Specification (1) is estimated with the spatial TSLS estimator developed in Kelejian and Prucha (1998). The standard errors are heteroskedasticity-robust, and the disturbances ε_{it} are assumed to be independent. No observed covariates other than the spatial lag of the price variable are included. In specification (2), we allow for spatial dependence in the disturbances of the model. This dependence could arise due to spatially correlated costs or demand characteristics.[28] The disturbances are modeled according to the standard spatial autoregressive model with autoregressive disturbances of order (1, 1) (SARAR(1, 1)), see e.g. Anselin and Florax (1995).[29]. The parameter η represents the coefficient of the spatial lag of the errors. Specification (3) includes additional observed covariates. In section C.4 in the online appendix, we present results obtained with alternative estimation methods (maximum likelihood and indirect inference), which do not

[27] w_{ii} is set to zero for all i.

[28] Ignoring spatial dependence in the error term would still lead to consistent estimator of the spatial lag parameter ρ, but it would lead to inconsistent estimators of the standard errors of the regression coefficients.

[29] The disturbances in a SARAR(1,1) model are specified as

$$\varepsilon_t = \eta M \varepsilon_t + \xi_t, \tag{10}$$

where M is a $n \times n$ spatial weights matrix and $\xi_t = (\xi_{1,t}, \ldots, \xi_{n,t})$ is a vector of independent innovations with variances $\sigma_1, \ldots, \sigma_n$.

Table 2: Empirical results, testing the SIH.

	(1)	(2)	(3)
ρ	0.65**	0.77***	0.55**
	(0.35)	(0.26)	(0.33)
Population			0.02
			(0.03)
Age > 65			-0.87
			(0.58)
Labour Cost			0.002
			(0.004)
Intercept	9.21	6.19	14.36
	(11.16)	(6.43)	(13.50)
η		0.40*	
		(0.21)	
Num of obs.	229	229	229
I-Stage F-stat.	15.83	14.79	21.29

Note: main results SIH. Price change is regressed on average price of neighbors. Specification (1) assumes independent disturbances, the standard errors are heteroskedasticity robust. Specification (2) is a SARAR(1,1) model. Specification (3) includes observed covariates. Weights are 1 for neighbors with shared border and zero otherwise (row standardized). * denotes $p < 0.1$, ** denotes $p < 0.05$, *** denotes $p < 0.01$. One-sided test p-values for $\hat{\rho}$.

depend on the validity of the instrument.

All three regressions produce a positive and significant estimate of ρ. The values vary between 0.55 and 0.77, thus all lying within the 90 % confidence interval around 0.65 (the intermediate estimate). Since we instrument for p_{-it}, $\hat{\rho}$ can be interpreted as a causal effect of the weighted average price p_{-i} in neighboring markets on the price in market i and is not due to spatial correlation of unobserved factors of demand and supply. On the basis of these results, a unit increase in p_{-i} induces between 0.55 and 0.77 units change in the price of firm i, so that the spatial spillover is economically strong. The robustness checks in section C.4 in the appendix provide very similar results.

The instrument is strong in all three regressions with the Kleibergen-Paap F statistics being between 14.79 and 21.29. The first stage results are summarized in table C.3 in the online appendix. As an example, the estimated coefficient of Z_{-it} in the first stage of specification (1) is positive and has the value 33.12. Under the assumption that this coefficient has a causal meaning, a unit increase in the change of customer stock led to a price increase of around 30 Swedish kronor. This corresponds to a 4% increase in the average price of DH in 2009.

The estimates of the effect of other observed covariates in specification (3) are not significant. The finding is not surprising given the lack of variation between 2008 and 2009 of these covariates, see table 6 in the descriptive statistics section in the appendix.

These results support our hypothesis, that firms homogenize prices in order to reduce complaints. Thus, threat of regulation creates relations between neighboring markets, markets that are unrelated when there is no threat of regulation. Note that we do not say how firms set their prices. The spatial price spillovers may result from collusion between local monopolists. Collusion in the Swedish DH sector is not prohibited by antitrust laws as these markets are considered economically independent. In addition, collusive behavior should be credible as it would allow firms to simultaneously increase prices (i) without triggering regulation (or, even stronger, precisely not to trigger regulation) and (ii) without reducing the number of individuals who connect to DH. A prerequisite for collusive behavior is a coordination mechanism, which might be a challenging task in a sector with over 200 local markets. It is beyond the scope of this study to empirically distinguish these coordination mechanisms.

5 Competing theories

The intangible nature of regulatory threat requires extra care to preclude misleading interpretations of our empirical results. In this section, we test against competing theories. A competing theory is a mechanism which produces a similar response (compared to the main model) with respect to manipulating the main independent variable, but a different prediction when another variable is manipulated, see e.g. Card et al. (2011).

We focus on mechanisms that have been discussed in the empirical literature on regulatory threat. These include threat of antitrust action and competition for new customers.[30]

Threat of antitrust prosecution. Firms might reduce their prices when they fear antitrust scrutiny. If customer complaints are used by the antitrust authority as a signal of market power abuse, then our empirical results from both sections 3.2 and 4.3 are compatible with threat of antitrust prosecution.

We have two arguments against this possibility. First, although possible, antitrust cases in the DH sector are very rare with only two cases since the deregulation in 1996 (2005 and 2006). Second, and more important, direct complaints to the Swedish Competition Authority were possible (i) before the debate about DH regulation intensified around 2005[31] and, in that course, (ii) prior to the establishment of the DHB. In addition, antitrust threat is less political than regulatory threat. As a result, threat of antitrust action can be considered stable from 1996 until today. This characteristics provides a source of discriminatory variation: if the patterns of firm behaviour that we found in the previous two sections (significant $\hat{\gamma}$ and $\hat{\rho}$) are due to fear of antitrust action, we should find similar patterns prior to the period of threat of regulation.

Since we do not observe complaints to the antitrust authority, we focus on the spatial interaction between firms. In particular, we estimate the spatial spillover effect ρ from (7) using data from the period 2004-2005. This time period is chosen for two reasons. First, in 2004-05 the debate about fair DH pricing was still not on the agenda - neither in the Parliament, nor in the media. Second, in 2004 a policy shock analogous to the 2008-subsidy triggered a change in the stock of DH customers.[32] We use this policy as an instrument for the endogenous spatial lag $\sum_{j \neq i} w_{ji} p_j$. Thus, we replicate our 2008-09 analysis in a setting with no regulatory threat.

Table 3 presents the results obtained with spatial weights defined as in (9). In the

[30] Another competing mechanism is threat of entry in contestable markets, see e.g. Acutt et al. (2001) and Stango (2003). However, this mechanism is not relevant for our study due to the natural monopoly character of DH.

[31] Abuse of market power in has been a violation of the Swedish Competition Act (2008:579) since

Table 3: Testing for spatial price spillovers under a No-Threat scenario.

	(1)	(2)
ρ	0.71	0.59
	(0.60)	(0.61)
Population		0.02
		(0.04)
Age > 65		1.85
		(1.70)
Labour Cost		
		(0.004)
Intercept	6.25	-1.68
	(12.81)	(13.57)
Num of obs.	215	215
I-Stage F-stat.	9.039	7.187

Note: price change is regressed on average price of neighbors. Data from 2004-2005. Equal weights for neighbors sharing a border, and 0 weight for all others. * denotes $p < 0.1$, ** denotes $p < 0.05$, *** denotes $p < 0.01$. One-sided test p-values for $\hat{\rho}$.

first regression, only the average price of neighbors is included as a covariate, whereas regression 2 includes two additional covariates (we do not observe labor cost for this period). The estimates of ρ are insignificant in both specifications.[33] This result contrasts our significant findings for 2008-09.This contrast is not compatible with price spillovers driven by fear of antitrust intervention, but it is consistent with threat of regulation that emerged after 2005.

is not consistent with the fact that threat of antitrust prosecution was stable over time, but it is consistent with threat of regulation that emerged after 2005.

Connection of new customers. Positive local correlation of prices could be generated by the firms' objective of attracting new customers (existing customers are locked in). Potential customers who perceive the DH price as unfair might opt for alternative heating options, see e.g. Rotemberg (2011). [34] This possibility may lead firms to reduce

1993.

[32]A description of the subsidy is provided in section E.1 in the online appendix.

[33]Alternative specifications yield similar results and are available from the authors upon request.

[34]In the context of threat of regulation, this mechanism was first discussed by Olmstead and Rhode (1985). Surprisingly, it has not been subject to discussion in other empirical papers on threat, and it

price differences across districts, just as in the case of threat of regulation. In order to disentangle the effect of a regulatory threat from that of this competition, we construct a measure of potential loss of customers. We take the (relative) increase in the number of constructed dwellings in a municipality during the coming three years, i.e. 2010-2013. The future growth in dwelling stock of a municipality is strongly correlated with the number of potential customers: in principle, each new dwelling is occupied by a new potential customer. Moreover, the short and middle term growth in the number of dwellings in a municipality is known in advance, as building permissions are typically granted 2-3 years before the completion of a building. We observe this growth for the years 2010-2013 and assume that it was perfectly known to the firms in 2009.[35] We then estimate ρ using the 50% of municipalities with the highest growth in dwelling stock. If the competition mechanism is responsible for the spatial price spillovers, we should see a (substantially) higher estimate of ρ for this subsample than for the full sample.

The results of two different specifications are shown in table 4. Both estimates $\hat{\rho}$ are very close in magnitude to the corresponding estimates when we use the full sample, and are also significant. Thus, they are not consistent with the competition mechanism.

has not been explicitly tested against.

[35] Building permissions can be observed by any citizen or organization and DH firms obviously have strong incentives to stay updated about construction plans of dwellings.

Table 4: Testing for spatial price spillovers with the subsample of the 50 % municipalities with highest future growth.

	(1)	(2)
ρ	0.70**	0.51*
	(0.35)	(0.37)
Population		0.0003
		(0.0002)
Age > 65		-1.36
		(0.88)
Labour Cost		-0.002
		(0.008)
Intercept	11.81	7.87
	(11.72)	(16.03)
Num of obs.	114	114
I-Stage F-stat.	9.907	11.41

Note: main results SIH. Price change is regressed on average price of neighbors. Specification (1) assumes independent disturbances, the standard errors are heteroskedasticity robust. Specification (2) is a SARAR(1,1) model. Specification (3) includes observed covariates. Weights are 1 for neighbors with shared border and zero otherwise (row standardized). * denotes $p < 0.1$, ** denotes $p < 0.05$, *** denotes $p < 0.01$. One-sided test p-values for $\hat{\rho}$.

A Appendix: descriptive statistics

A.1 Descriptive statistics

This section contains tables with descriptive statistics.

Table 5: Summary statistics of of the sample used to test the RTH (2010-2013)

Variable	Min	1st Qu	Median	Mean	3rd Qu	Max
Price	444.47	763.76	808.74	805.75	855.87	1163.23
Population	965	4747	8463	75 954	21 725	1469131
Labor cost	22 892	25 009	25 689	25 779	26 452	30 744
Age > 65	0.12	0.20	0.23	0.22	0.25	0.32
Complaints	0	0	0	0.19	0	81
Unanticipated disruptions	0	0	0	2.57	1	197

Note: summary based on 927 observations.

Table 6: Summary statistics of the sample used to test the SIH (2008-2009)

Variable	Min	1st Qu	Median	Mean	3rd Qu	Max
Price 2009	423	678.3	743.5	728.7	783.6	912.1
Price 2010	437.8	711.5	771.7	761.2	818.1	964.9
Rel. Δ Price	-0.10	0.024	0.042	0.045	0.059	0.28
Rel. Δ Population	-0.014	0.0006	0.002	0.003	0.005	0.023
Rel. Δ Electricity	0.0477	0.0477	0.0477	0.0478	0.0477	0.0482
Rel. Δ Labor cost						
Rel Δ Age > 65	-0.054	-0.019	-0.009	-0.011	-0.003	0.016
Z_{i2009}	0.025	0.21	0.62	0.60	0.71	0.84

Note: Rows 3-8 contain statistics for the relative change (Rel. Δ) 2008-09 of a variable. Z_{i2009} is the local share of detached houses in 2009. Summary based on 225 observations. Prices determined in 2008-09 observed in the subsequent year (2009-10, respectively).

Table 7: Summary statistics of of the sample used to test equation 4 (2009-2014)

Variable	Min	1st Qu	Median	Mean	3rd Qu	Max
Price	536.5	743.61	795.9	786.17	839.63	1163.23
Population	1017	4794	8464	77 927	21 494	1469131
Labor cost	23 089	24 631	25 200	25 363	26 000	30 744
Age > 65	0.13	0.19	0.22	0.22	0.24	0.32
Complaints	0	0	0	0.0731	0	81
Share fuel 1	0	0	0	0.071	0.033	0.99
Share fuel 2	0	0.0001	0.0007	0.0022	0.0023	0.15

Note: fuel 1 = fuel from waste heat, fuel 2 = oil fuel. Summary based on 1519 observations.

Table 8: Summary statistics of the sample from 2003-2004

Variable	Min	1st Qu	Median	Mean	3rd Qu	Max
Price 2004						
Price 2005	426.74	652.42	708.69	710.89	768.91	884.92
Rel. Δ Price	-0.10	0.024	0.042	0.045	0.059	0.28
Rel. Δ Population						
Rel Δ Age > 65	-0.07	-0.03	-0.02	-0.02	-0.0168	0.0115
Z_{i2004}						

Note: Rel. Δ denotes the relative change in 2003-04 (for prices in 04-05) of a variable. Z_{i2004} is the local share of detached houses in 2004. Summary based on 225 observations. Prices determined in 2003-04 observed in the subsequent year (2004-05, respectively).

A.2 Missing prices in 2008-2009 and the resulting threat to internal validity

Despite the political weight of the NHS in matters concerning DH, reporting of the prices to the SPA is not legally mandatory. As a result, some of the firms do not report or report only occasionally. We exclude firms for which we do not observe the price in 2008/2009 from the main empirical analysis. Furthermore, we exclude firms that do not connect detached house, as these observations have a missing instrument value. In addition, firms that operate in several markets have also been dropped. In order to analyse how this exclusion influences the internal validity of our main results, we test for equality of observed covariates of included and excluded observations. This comparison is presented in Table 9. The last column contains the p-value for the t-test for comparison of means.

Table 9: Comparison of averages for covariates: excluded vs included observations

Relative change	included	excluded	p-value
Population	0.003	0.0.0035	0.56
Labor cost	0.0141	0.0146	0.80
Age $>$ 65	-0.0107	-0.0116	0.66

B Appendix: RTH

C Appendix: SIH

C.1 Economics and Econometrics of the choice of the spatial weights

The choice of the spatial weights matrix $W = (w_{ij})_{i,j=1,\ldots,n}$ is motivated by the following two arguments. First, information costs are lowest when customers compare prices with direct neighbors. Local newspapers are the major source of information on DH prices.

Table 10: Regression of unanticipated service disruptions on observed factors of demand and supply

$Y = D_{it}$	Coef.	Std. Err.	t	p-value	[95% Conf. Int]	
$\hat{\beta}_0$	25.40	16.61	1.53	0.127	-7.31	58.11
HDD	-0.00006	0.0002	-0.29	0.77	-0.0005	0.0004
# Households	0.0006	0.001	0.67	0.51	-0.001	0.003
Population % > 65	60.13	66.13	0.91	0.36	-70.09	190.36
Av. Income	-0.14	0.09	-1.54	0.125	-0.309	0.038
Fixed effects	Yes					
Num of obs:	777					
Prob> F:	0.17					

Table 11: First stage results for the corresponding IV results in table 1.

	(1)	(2)	(3)
D_{it}	0.049** (0.02)	0.052** (0.02)	0.052** (0.02)
Population			0.04 (0.35)
Age > 65			13.79 (99.46)
Labour Cost			0.0003 (0.0008)
Year dummies	Yes	Yes	Yes
Fixed effects	Yes	Yes	Yes
Num of obs.	927	927	927
F-stat.	4.79	4.74	4.62

Note: Specifications (1)-(3) display the first stage estimates to specification (2)-(4) from the main results, respectively. * denotes $p < 0.1$, ** denotes $p < 0.05$, *** denotes $p < 0.01$.

These newspapers typically cover 2-4 municipalities.[36] Moreover, a big share of the working population commutes to one of the neighboring municipalities.[37] In addition, in Sweden, there are 72 local labor markets (data 2014) defined on an administrative

[36] A report on the Swedish media landscape in Sweden can be found on the webpage of the European Journalism Centre, http://ejc.net

[37] A detailed database on regional patterns of commuting in the Nordic Countries can be found under the link http://www.grs.scb.se.

basis, which corresponds to 4.03 municipalities per labor market on average - close to the average number of direct neighbors of a municipality.[38] Thus, obtaining information on DH prices from direct neighbors seems a natural choice. If consumers consider the local specifics of infrastructure, weather conditions and labor markets as determinants for the DH price, the closest neighbors may in fact be also the only source of information they choose.

The second argument is of econometric nature and considers the robustness of estimates to changes of the weight matrix. If a matrix W_1 is changed to W_2, then the difference of the estimates of the spatial lag coefficient ρ based on W_1 and W_2 will depend on the correlation coefficient of $W_1 P$ and $W_2 P$, where $P = (p_1, \ldots, p_n)'$. Moreover, this difference depends continuously on the correlation coefficient, implying that small changes of a weight matrix will produce very similar results. In addition, a random measurement error in the elements of the weight matrix does not change the asymptotic properties of the estimator, in particular its consistency.

C.2 Evidence that the change in demand stock is a valid instrument

C.2.1 Descriptive statistics for the instrument

The histogram of the empirical distribution of $Z_{i,2009}$ is depicted in Figure 2. Summary statistics are presented in table 6 in this online appendix. Roughly 90% of all values of $Z_{i,2009}$ lie between 0.2 and 0.8. The minimum of Z_i is 0.025 and the maximum is 0.84, with an average of 0.599 and 3rd quartile of 0.71. These descriptive statistics provide evidence that $Z_{i,2009}$ has a rich variation over its possible support $[0, 1]$. Figure 3 presents the spatial distribution of $Z_{i,2009}$, with darker colour indicating values closer to one and white regions indicating missing prices.

[38] This information is obtained from the Swedish Statistics Institute, http://www.scb.se/

Figure 2: Histogram of the demand shock Z_i.

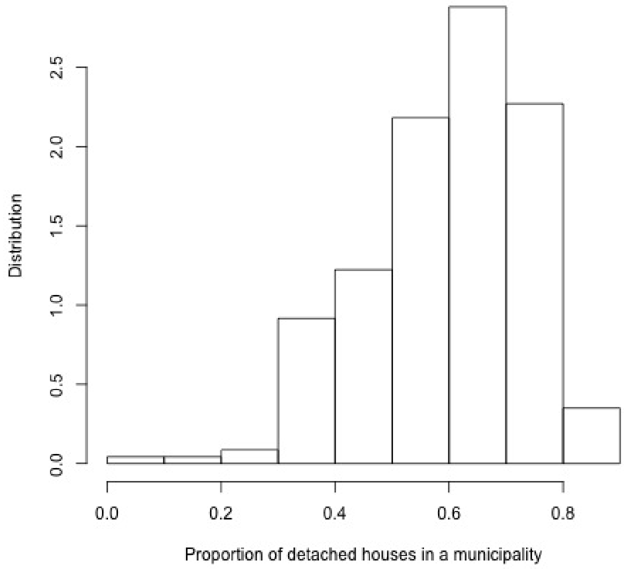
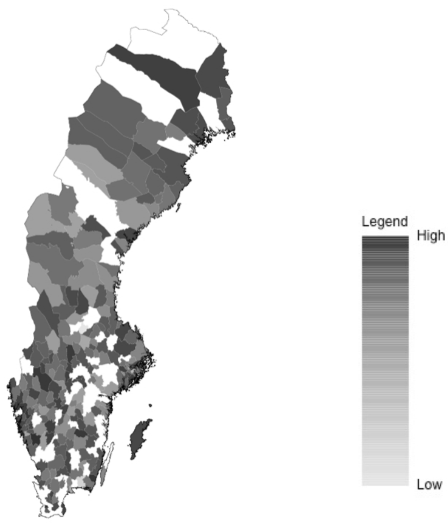


Figure 3: Spatial distribution of the instrument.



C.2.2 The substitute

The only substitute of district heating is electricity based heating. The electricity price paid by end-consumers consists of three parts, the observable electricity tax being one of them. Table 6shows that the increase in electricity tax in 2008-09 has practically no cross-sectional variation. The other two components are the retail price and the local distribution price. The retail price is determined on a highly competitive international market (the so called Nord Pool electricity retail market) and has practically no local variation, see Botterud et al. (2010) for a detailed description of the Nord Pool market. The local distribution price is regulated and has no increase in the period of observation. It is therefore captured by the fixed-effects θ_i. As a result, the price of the substitute has no time and regional variation for the period of consideration and is therefore not correlated with the demand shock $Z_{i,2009}$.

C.2.3 Regression of instrument on observed covariates

Table 12: Regression of potential change in customer stock on observed covariates

	Coef.	Std. Err.	t	p-value
Intercept	0.57**	0.024	22.98	2e-16
Population	-0.00001^{***}	4.82e-06	-2.51	0.51
Age>65	5.04e-06	2.32e-05	0.217	0.82
Av. Income	0.004	0.003	1.32	0.19
Num of obs:	228			

C.3 First stage results of main regression, SIH

Table 13: First stage results corresponding to the IV estimation in table 2, section 4.3 in the main paper.

	(1)	(2)	(3)
Z_{it}	33.12*** (7.395)	35.30*** (8.16)	30.46*** (12.45)
Population			0.09 (0.56)
Age > 65			3.67 (14.56)
Labour Cost			0.0003 (0.0012)
Num of obs.	229	229	229
F-stat.	15.83	14.79	21.29

Note: Specifications (1)-(3) display the first stage estimates to specification (2)-(4) from the main results, respectively. * denotes $p < 0.1$, ** denotes $p < 0.05$, *** denotes $p < 0.01$.

C.4 Robustness checks SIH

In this section, we provide additional evidence for the spatial price spillovers (SIH) documented in the main paper. Table 14 contains results from 5 additional specifications. In columns (1), the estimates are produced with a spatial TSLS estimator as in specification (1) of the main results (table 2 in the main paper), but with different weights. In particular, the weights are specified as

$$w_{i,j} = \begin{cases} 1/d(i,j) & \text{if municipality } j \text{ shares a border with municipality } i \\ 0 & \text{otherwise,} \end{cases} \tag{11}$$

Here, $d(i,j)$ denotes the distance (e.g. in km) between the local monopolies in municipalities i and j. The design of the weight matrix reflects the intuition, that the cost of search increases proportionally with the geographical distance to the neighbor.[39] The weights are row standardized, so that their sum is 1.

[39]Results obtained with weights $w_{i,j} = 1/d(i,j)^{0.5}$ and $w_{i,j} = 1/d(i,j)^2$ are very similar and obtainable upon request from the authors.

Colums (2) - (5) present results obtained with methods that do not depend on (the validity of) the instrument. These methods are maximum likelihood (ML) and indirect inference (II). Colums (2) - (3) contain the ML estimates with weighting schemes equal to (9) from the main results (equal weights for bordering neighbors) and (11) from the robustness check presented above in this appendix (proportional to distance to bordering neighbors), respectively. The asymptotic distribution of ML depends on the iid assumption of the disturbances, as well as on a parametric specification of their distribution, see LeSage and Pace (2014).

Columns (4) - (5) present results obtained under the above weighting schemes but with an Indirect Inference method (II). The II approach implemented here is based on the theoretical results of Kyriacou et al. (2014). This is a simulation method that can be described in the following way. Suppose that the "true" parameter ρ_0 lies in a closed subset Λ of $(-1, 1)$. For any element ρ of Λ, generate K datasets $y_1(\rho), \ldots, y_K(\rho)$, each of them following the model .[40] For each data set $y_k(\rho)$, calculate the OLS estimator of ρ_0, $\hat{\rho}_k(\rho)$. Then, the II estimator is defined as

$$\hat{\rho}_{II} = argmin_{\rho \in \Lambda} \mid \hat{\rho}_{OLS} - \frac{1}{K} \sum_{k=1}^{K} \hat{\rho}_k(\rho) \mid, \tag{12}$$

where $\hat{\rho}_{OLS}$ is the OLS estimator of ρ using the true dataset. Kyriacou et al. (2014) derive the asymptotic normality of the estimator without relying on a parametric assumption of the distribution of the disturbances, but requiring that they are iid and that there are no covariates other than the spatial lag of the dependent variable. One drawback of this method is that Kyriacou et al. (2014) do not provide a method to compute the standard errors.

The first column contains estimates with a weight matrix as in the main specification, while in the second the weight matrix W3 has been used. $\hat{\sigma}$ denotes the estimate of the

[40] The error term is generated from the normal distribution.

Table 14: Robustness checks SIH.

	(1)	(2)	(3)	(4)	(5)
$\hat{\rho}$	0.67** (0.38)	0.21*** (0.079)	0.20*** (0.076)	0.25	0.27
Intercept	8.69 (11.93)	19.90*** (6.11)	20.06*** (6.12)	15.23	15.76
First stage F-stat	13.038				
Num of obs.	229	229	229	229	229

Note: Specifications (1): IV estimates under weights proportional to (1 over) distances to closest neighbors. Specifications (2)-(3): ML estimates with equal (2) and proportional to distances (3) weights. Specifications (4) - (5): Indirect Inference results with equal (4) and proportional to distances weights (5). * denotes $p < 0.1$, ** denotes $p < 0.05$, *** denotes $p < 0.01$ One-sided test p-values for $\hat{\rho}$.

asymptotic standard error of the disturbances. The p-values are in parenthesis. The results under the two specifications are very similar, with the estimate of the spatial coefficient being positive and significant, but smaller than the estimates produced with the instrument.

D Appendix: testing the complaints generating mechanism

To test the assumption (4) from the main paper, we specify the model

$$C_{it} = \alpha_0 + \alpha d_{it-1} + X_{it}\delta + \sum_{l=1}^{T-1} \tau_l T_l + \eta_i + \nu_{it}, \tag{13}$$

where d_{it} is defined as $p_{it} - \sum_{j \neq i} w_{ij} p_{jt}$. It gives the difference between the price set by firm i and the weighted average of the prices of its neighbours. Thus, we expect α to have a positive coefficient, and define the Null hypothesis $H_{0,A} : \alpha \leq 0$.

To account for potential endogeneity of d_{it}, we use two cost shifters as instruments. Since C_{it} is determined on the demand side, a cost shifter would be a valid exclusion restriction. This line of reasoning follows the standard IV identification in the demand estimation literature. We use (i) the share of wasted heat of the total annual amount of fuel used by a DH firm and (ii) the share of oil on the total annual amount of fuel as instruments. Waste heat is a byproduct in industrial processes and sometimes it can be fed into the DH system to provide a cheap source of complimentary heat. Oil, on the other hand, was the most common fuel type in Swedish DH systems until the 1980s. Now the average share is less than 15% and it is primarily used as startup fuel and to meet peak demand during cold periods. The marginal cost of oil is relatively high and DH firms are likely to adjust their prices whenever using higher shares of it.

Table 15 presents the results of four different specifications. Specifications (1) and (2) are obtained under equal weights for all bordering neighbors, whereas (3) and (4) under weights proportional to the distance to the bordering neighbors. The instruments used in to produce the results in table 15 are Share of heat, Share of Oil and Share of Oil squared. We use the limited maximum likelihood (LIML) estimation method due to its slightly better properties in finite samples.

The estimates of α are very similar in all four regressions. They are positive and significant at the 10% level (p-values are calculated for a one-sided test corresponding to the hypothesis tested). An increase of 75 SEK (roughly 10% of the average price) would increase the number of complaints in a market by 0.14 complaints. This appears at first to be a very small number. We note however that the average number of complaints per municipality and per year is 0.19. Therefore, an increase of 0.14 complaints corresponds to more than 10 % of the average number of complaints per municipality for the whole period, and more than 50% of the average number of complaints per municipality and per year. This finding provides evidence that customers use neighboring prices as reference prices in order to learn about the fair price of DH. Big positive difference to neighboring prices is considered unfair and penalized with complaints.

Table 15: Empirical results, testing the complaints generating hypothesis (4).

	(1)	(2)	(3)	(4))
Price difference	0.0014*	0.0014*	0.0015*	0.0015*
	(0.0011)	(0.0011)	(0.0011)	(0.0011)
Population		-1.08e-06*		-1.09e-06*
		(5.87e-07)		(5.82e-07)
Age > 65		0.763		0.796
		(0.939)		(0.955)
Labour Cost		0.000		0.000
		(0.00001)		(0.000014)
Year dummies	Yes	Yes	Yes	Yes
Fixed effects	Yes	Yes	Yes	Yes
Num of obs.	1519	1519	1519	1519
I-Stage F-stat.	5.23	5.15	4.76	4.71

Note: Specifications (1) and (2) are obtained under equal weights for all bordering neighbors, whereas (3) and (4) under weights proportional to the distance to the bordering neighbors. HAC-robust errors in all specifications. * denotes $p < 0.1$, ** denotes $p < 0.05$, *** denotes $p < 0.01$. One-sided test p-values for the Price difference variable.

E Appendix: Is what we measure really threat?

E.1 Description of the energy efficiency subsidy in 2004-2005

The Swedish Government decided on the 15 April 2004 to offer a subsidy that home-owners could use for all repair, conversion and extension works that improved the energy efficiency of their houses. The subsidy could be claimed from the 15 April 2004 until the 31 June 2005. No Parliamentary debate proceeded the implementation of the subsidy, but the Government presented and implemented the subsidy on the same day, i.e. 15 April. The maximum amount home-owners could receive was 30% of the labor cost, or 10500 SEK for single family (detached) dwellings and 5000 SEK for apartments in attached buildings.

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