UNIVERSITY OF GOTHENBURG
SCHOOL OF BUSINESS, ECONOMICS AND LAW

Master Degree Project in Economics

The Effect on House Prices of the Remediation of Contaminated Areas

A study of the Falu mine in Sweden

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Master Degree Project No. 2016:98
Graduate School

THE EFFECT ON HOUSE PRICES OF THE REMEDIATION OF CONTAMINATED AREAS - A study of the Falu mine in Sweden

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May 2016

Abstract

Our thesis aims to measure how a local population values the effect of remediating a contaminated site to strengthen the argument for remediation. We estimate the effect of remediation processes of the Falu mine in Sweden on sales prices of surrounding houses and estimate the willingness to pay of the local population for the cleanup. We find that after remediation, residential property prices in the remediated area increased by 6.9 percent more than prices of houses located outside the remediated area. We estimate that the aggregated profit for the increase in price on the total land area owned by homeowners in the remediated area is SEK 100,725,965 SEK, which exceeds the governmental costs of remediation of the Falu mine.

Handelshögskolan I Göteborg

We would like to thank our teachers from Handelshögskolan in Gothenburg, Sweden, for their guidance and support throughout the course of this project.

A special thank you to Cathrine Lundin and Jonas Fors from Naturvårdsverket (Swedish EPA) for providing us with internal data and knowledge about the Swedish mines in our study.

We would also like to thank Fredrik Engström and Maria Bohm from Riksrevisionen for their expert view on the topic.

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I. Introduction

This study uses hedonic pricing to estimate the effect on house prices of governmental cleanups of contaminated sites and estimates the monetary benefits of cleaning up. Hedonic price models are widely used to determine demand or monetary value of environmental services that affect market prices. The model is based on the assumption that the price of a good depends on its characteristics or the services it provides. We can value a specific characteristic of a good by looking at how much people are willing to pay for a change in that characteristic. Examining the relationship between sanitation of a contaminated site and the price of properties located in the sanitated area before and after the cleanup of the area is a tool to measure people's willingness to pay for a cleaner environment and to eliminate health risks.

We focus our study on the Falu mine located in the center of the city of Falun in Sweden, which closed in 1992 after 1000 years in activity. It was one of the largest sources of metal waste in Sweden, leaking heavy metals like copper, lead, zinc and cadmium into the grounds and waters. The same year the mine closed, Stora (the mining company in Falun) and the Swedish government committed to share the costs of remediation in and around the Falu mine. The total cost for the remediation period was 166 million SEK, of which 98 million SEK were paid by the Swedish government between 2004 and 2009. As a part of the remediation process a water collection system supposed to clean all of the heavy metal contaminated water leaking from the mine started running in 2008. Since the system began operating, the heavy metal leakage to the center of Falun significantly decreased.

We analyze the effect of the water collection system on housing prices for the properties that were directly affected by the cleaner water. We use a difference-in-difference model to estimate the hedonic price for the remediation and find that after the announcement of the end of the cleanup, residential property prices on the remediated grounds in Falun increased by 6.9 percent more on average than houses that were not affected by the remediation. We then calculate the average profit per square meter land area for a homeowner living in the remediated area, which is 173.48 SEK. The aggregated profit for the total affected land area is SEK

100,725,965, which exceeds the governmental expenditure of remediation. To our knowledge, there is no previous research examining these monetary effects in Sweden.

83% of Sweden's total waste was produced by the mining industry in 2012. It is by far the largest waste sector, representing 13,5 ton per person per year in Sweden. The greatest environmental problems caused by the mining industry in Sweden today result from old heaps that were left uncovered and that are in need of full governmental funding for remediation. The amount of mines in activity has gone from around 100 to 16 in the last fifty years, leaving many heaps uncared for. An audit report published in December 2015 by the Swedish National Audit Office (Riksrevisionen) points out the importance of the mining waste issue for the Swedish environment. Twenty-seven old mines in Sweden require remediation at an estimated cost of between 790 and 1400 million SEK, a large part of which the government would have to stand for since no operator can be held accountable for the closed mines. The audit does however not suggest any channels to do so nor motivates the economic and societal benefits of remediating old mining sites.

To perform our study we collected data on the Falu mine from the Swedish EPA, including the coordinates of the mine, the type of pollution, the start and end dates for sanitation, and the risk class (indicating the magnitude of the impact on health and environment) of the mine. We purchased data containing information about all houses sold between 1996 and 2014 in the municipality of Falun from the Swedish Lantmäteriet (the Land Registry). The data contained the sales price and the sales date of each house, its square footage, coordinates, total land area and assessed property value. Our analysis is limited to houses located in central Falun, which is within 3 km of the mine and sold between 2006 and 2012, three years before and after the end of the cleaning up process of the mine in 2008. 744 house sales are observed over the period, 351 of which are located within the remediated area.

The study proceeds as follows. Section II discussed the previous literature on the topic of contaminated sites. Section III provides background information about mining in Sweden, in particular about the Falu mine, and discusses the environmental consequences in the municipality of Falun due to the mining activities. In section IV we describe the process of the data collection and provide some summary characteristics. Section V provides graphical evidence and presents the model specification as well as the econometric identification problems related to it. In section VI we present the estimation results from these specifications and perform a robustness check in section VII to validate our results. A cost-benefit analysis of the cleaning up process in Falun is made in VII. Finally, we conclude in section VIII and discuss the policy implications.

II. Related Literature

One approach to estimating the benefits of cleanups that has been widely used is looking at housing prices and estimating the perceived risk of being exposed to a contaminated site. Early research estimates the effect of proximity to a contaminated site, while more recent research estimates the effect of cleanups, but there is yet to be a consensus. For example, early research suggests that housing prices are significantly lower for areas close to a contaminated site implying a large proximity discount, while more recent research measuring the effects of cleanup claims that the "proximity discount" is not fully eliminated after remediation. Additionally, a vast majority of the empirical work has been based on American data and the American superfund program (Sigman and Stafford 2011). Kiel and Williams (2005) show that the proximity discount differs from site to site. Their results from the investigation of Superfund sites in the US show that some sites have a negative effect on housing prices, as expected, but that in some cases the effect is non-existent or even positive.

Kiel and Zabel (1999) find that the economic benefits of cleaning up their studied Superfund sites was approximately 150 million dollars (1992 dollars). That amount is greater than the present value of the costs of the clean up, showing efficiency and positive benefits to society. Greenstone and Gallagher (2005) suggest that the "proximity discount" is not eliminated after cleanup. They do not claim that remediation has no effect on housing prices, but they argue that the benefits of superfund cleanups are much lower than the costs, using housing prices as a measurement tool.

Greenstone and Gallagher (2005) estimate the benefits of cleanups of 400 hazardous sites included in the American Superfund program. Similar to Kiel and Williams (2005) they use a property value approach based on a hedonic price model to estimate these effects on a more aggregate level compared to previous research, which have focused on single or a few sites. They closely follow the methodology used by Kiel (1995) and Kiel and McClain's (1995) to estimate the hedonic regressions but include all Superfund sites in the chosen counties instead of particular ones. Kiel and Zabel (1999) estimate the benefits of only 2 sites in the Superfund program but with housing information from 2000 properties. Kiel and Williams (2005) go further in their study by doing a meta-analysis to explore why some sites have a negative effect on local properties and others do not. They look at differences in sites as an explanation to the different results.

Since there is yet to be a consensus on the effects of contaminated sites on housing prices and no previous research in Sweden on the topic, we see that our thesis can contribute to the empirical research by testing existing methods on new data.

III. Mining in Sweden

A. Background

Mining is a harmful activity to the environment, operating a mine under a short period of time has severe long-term environmental impacts. The most evident effects are the noise and dust produced, the effect on landscape, the pollution of air, watercourses, lakes and groundwater as well as the large amount of energy required. However, the most significant threat to the environment from the mining industry is linked to the management of mining waste. According to the Swedish EPA, Swedish mines produced 129 million tons of waste in 2012, which accounts for 83% of the total waste produce in Sweden. Hazardous substances in mining waste can contaminate the soils in surrounding properties and induce health risks if the contamination spreads through ground waters or by other means.

Two kinds of ores are produced from Swedish mines: sulfide ores and oxidic ores. After separation of valuable minerals and metals from the ore, the remaining residue is deposited in vicinity of the mines. The most critical problem to the environment is the residue from sulfide ores because of its content: iron sulfides. If left uncovered, iron sulfides oxidize into sulfuric acid and leak out to the environment as Acid Mine Drainage. The highly acidic Acid Mine Drainage water causes disturbances to the ecosystems such as water contamination, disrupted growth and disrupted reproduction of aquatic plants and animals as well as corrosion on infrastructure. It is especially harmful because it can occur long after the mining activities have ended.

As well as causing ecological concerns, Acid Mine Drainage causes economical concerns. Regions that are impacted often see lowered numbers of recreational fish, such as trout, and less outdoor recreational activities and tourism (U.S. EPA). These risks can be reduced by a cleaning up process of the contaminated mining grounds, which in turn improves the quality of the neighboring properties also affected by the contamination.

B. The Falu Mine

Mining in Falun is thought to have started around 850-1050. In 1200, the mine grew to an industrial level and was for a long time one of the most lucrative companies in Sweden. It is most commonly and historically known for its copper production. When the mine closed in 1992 after over 1000 years of mining operations, an estimated 400 000 ton copper, 500 000 ton zinc, 160 000 lead, 380 000 ton silver and 5 ton gold had been produced (*Lindeström, 2002*).

However, the Falun mine and its tailings were at early stages identified as the largest source of metal waste in Sweden. In its 1000 years in activity, roughly 6 million ton sulfur dioxide was released into the atmosphere and between 0.5 and 1 million ton heavy metals like copper, lead, zinc, cadmium leaked out into the grounds and waters. In 1968, the Swedish Environmental Protection Agency and the operating mining company, at the time called Stora Enso (now Stora), combined their efforts to assess and map out the amount of discharge originating from the mine. They estimated an average annual discharge of 550-ton zinc and 22-ton copper. They proceeded to form a joint venture with the aim of reducing Acid Mine Drainage from the mine and gathering information on the necessary remediation steps to take in the future.

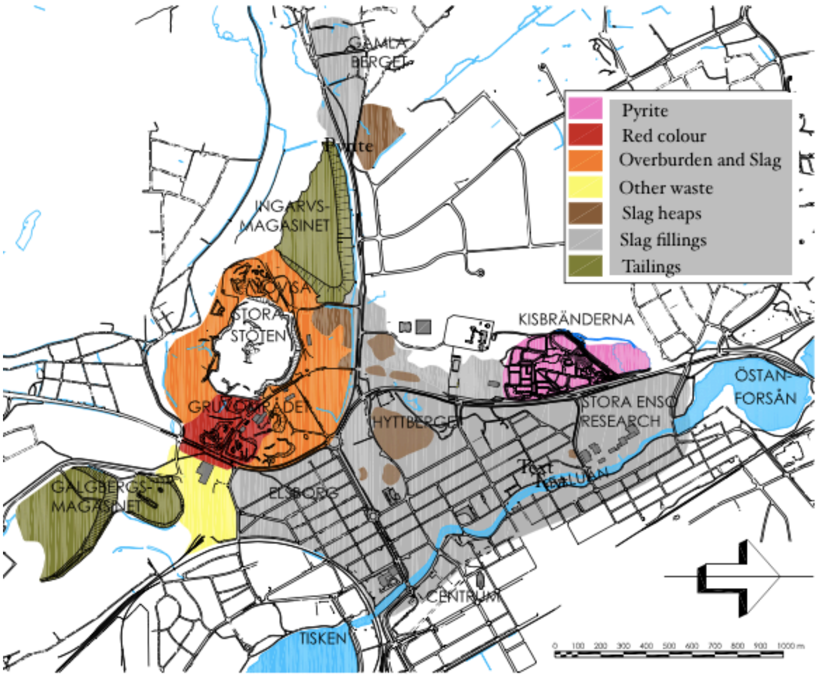

Figure 1 - Mine waste spread in Falu city (Hanæus and Ledin, 2004)

It is established that mining companies are responsible for the costs of remediation of their mining grounds, according to the Polluter Pays Principle (PPP). However when a mine has been closed for a long period of time and no company can longer be held accountable, or when a mining company has filed for bankruptcy or cannot fulfill its obligation, the government has a responsibility to intervene and assure the after-treatment of the grounds and reduce environmental damages.

In 1992 when the mine closed, Stora and the Swedish government agreed to the so called Faluproject to share the costs of remediation in and around the Falu mine and implemented a fifteen year timeline and monitoring strategy. The following remediation steps were taken (*Swedish EPA report, 2010*):

- In situ flushing and covering of the Pyrite Cinder Disposal Site by the old suphuric acid plant (1994-2007)
- Covering of the Ingarvet Tailings Pond (1997-2004)
- Relocation of red pigment raw material stores (1993-2007), construction of diversion ditches to limit the inflow of groundwater into the mine site (1996), and installation of an AMD collection system (2006) so that the mine water can be treated “throughout the future”.
- Testing and optimization of the AMD collection system (2007-2008)

While all mining operations ended in 1992, the after-treatment of the grounds around the mine is still ongoing. The city of Falun became part of the UNESCO World Heritage in 2001 and incorporates the mine and its waste heaps in the protected sites. Remediation processes that create too much change in the cultural environment are therefore difficult to perform, like the covering and moving of slag and waste heaps.

C. Environmental Consequences of the Falu Mine

The water rich in heavy metals leaking from the Falu mine area mainly flows out into the Falu River. Up until 1987 the water from the mine was conducted to the river without being treated, containing large amounts of metal from the mine and the mining waste. As a consequence, the water contains low levels of organic material.

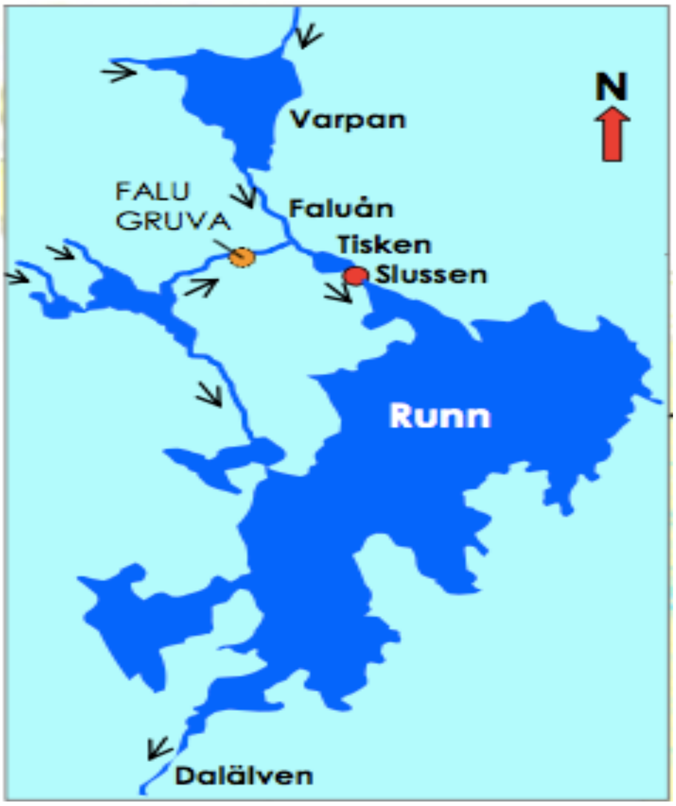

Figure 2 - Dalälvens catchment area (Lindeström and Tröjbom, 2010)

Emissions of metals to the water have continued even after the Faluproject. In fact, in the early 1600 the river around Falun was 75 meters wide compared to 15-25 meters in 2003 due to deposits of mine waste along the riverbank. In 2004, there was an estimated total of 7 million m^3 mining waste in the center of Falun (Hanæus and Ledin, 2004). Large amounts of mining waste have still not been removed, whether in visible heaps (that are part of the cultural heritage) or under the grounds and roads.

Figure 3 shows the heavy metal leakage from the mine, indicated by the red arrows. The blue arrows show the directions in which the water flows in the streams surrounding the mine (small amounts of heavy metals escape this way too). The heavy metal enriched water flows from the mine towards the center of Falun until it reaches the Falu River from where it continues to flow to Lake Tisken.

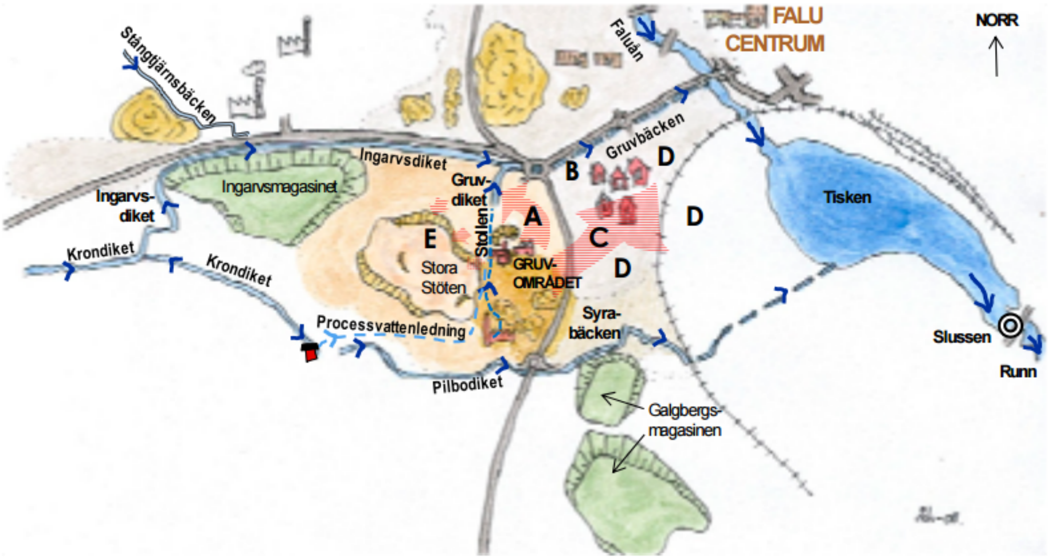

Figure 3. Contaminated water flow from the Falu mine(Hanaeus 2010)

Environmental conditions in the Falu River have improved since the implementation of the Faluproject. The aquatic vegetation has already become lusher and the amount of fish and fish species has increased. This indicates a certain improvement; certain fish species that were not able to reproduce in the contaminated waters have been reintroduced. However, the biomass is lower and the size of the fish is smaller than the national average, which can be due to the toxicity of the environment or a lack of nutrients in the animals' food due to contamination. The extreme conditions that the river was exposed to will have long-term effects on various parts of the ecosystem.

Water samples collected from the Falu River show that the remediation processes decreased the amount of heavy metals in the center of the Falun city by 80-90% for zinc and cadmium and 60-70% for copper. The levels of zinc, cadmium and copper in lower parts of the Falu River have decreased by 50-80% since the start of the Faluproject and remained at a constant level from the early 2000 until 2006 when the heavy metals leakage increased dramatically. The large heavy metal leakage in 2006 happened during the installation process of an Acid Mine Drainage collection system when large amounts of water managed to flow out from the mine. The Acid Mine Drainage collection system is constructed to clean all the water flowing out from the Falu mine. The system was tested and optimized and started running from mid-2008. The installation of the Acid Mine Drainage collection system resulted in a significantly lower leakage after 2008. In table 1 below the yearly amount of leaked heavy metals is presented. In the future the collection system should almost completely eliminate the outflow of heavy metals.

GRUVDIKET	Antal	Medelflöde	Zn	Fe	Cu	Cd	Pb
F8	värden	(l/s)	(ton/år)		(kg/år)		
1992	8	1,7	3,0	136	221	4,9	12
1993	12	1,4	3,2	167	290	5,8	
1994	12	0,80	6,9	75	734	13,2	
1995	6	0,32	2,6	17	270	5,0	
1996	5	0,72	2,9	15	423	6,0	
1997	6	1,1	2,1	12	235	4,8	
1998	8	0,38	4,2	23	539	8,5	
1999	6	0,91	4,2		540	8,9	
2000	9	0,49	6,4		831	12,8	
2001	12	0,41	6,8		837	13,1	
2002	12	0,49	6,6		790	13,3	
2003	10	0,45	5,6		652	9,1	
2004	10	0,38	5,2		649	9,4	
2005	11	0,27	4,2	21	489	8,6	1,2
2006	5	2,8	14,2	79	3160	28,6	3,4
2007	8	5,5	1,6	8,6	357	3,1	0,54
2008	12	0,73	0,5	1,1	134	1,4	0,32

Figure 4. Yearly amounts of leaked metals (Hanaeus 2010)

The total remediation cost for the period was 166 million SEK of which Stora paid 68 million between 1992 and 2004 and the remaining 98 million SEK were paid by the Swedish government between 2004 and 2009.

IV. Data

To conduct our analysis, we collected data from multiple sources. The description is presented below.

The Swedish Environmental Protection Agency provided information about four Swedish mines that have been remediated by the government or that still are in the remediation process: the Gladhammar mine, the Nautanen mine, the Falu mine and the Saxberget mine. The information includes the coordinates of each mine and of the respective pollution heaps, the type of pollution, the start and end dates for sanitation, and the risk class of the mines.

We purchased data containing information about all houses sold between 1996 and 2014 in the municipalities of each mine from the Swedish Lantmäteriet (the Land Registry). The data included the sales price and the sales date of each house, its square footage, coordinates, total land area and assessed property value. The assessed property value of properties in Sweden is based on an assessment of land value and building value and divided into different value areas in which homogenous houses have the same value level. The value of a house in a certain value area is calculated following a model that includes several criteria:

- Land criteria: size, water and drain (drinking water and toilet water), type of house (detached house, semi-attached house, town house) proximity to beach (distance to beach, lake or stream).
- House criteria: size (square meters of living space and additional space), age, standard, type of house.

We then transformed the coordinates of each home from the longitude/latitude coordinate system into the Swedish Sweref99 coordinate system and were able to calculate the exact bird fly distance from each house to the mines by using the Pythagoras equation.

After analysis of the data, we concluded that the locations of the houses in the municipalities of the Gladhammar, Nautanen and Saxberget mines were too distant from their respective mine to extract trustworthy results. What is more, the observed year intervals on the housing data did not correspond to the mining data for the Saxberget mine. We therefore decided to filter the data and focus our analysis solely on the Falu mine. The advantage of the Falu mine is also that it is located in the center of the city of Falun and, as being a world heritage site, is at the center of attention of the municipality and its population, which we believe can lead to a larger impact on property prices.

The houses were then categorized into the different neighborhoods of Falun by using the house coordinates and a map; the relative homogeneity of homes within each neighborhood allows us to control for unobserved fixed and time varying characteristics at the neighborhood level. The categorization also allows us to distinguish between the treatment and the control group. This is further discussed in section V-A.

Table 1 - Characteristics of homes sold in Falun municipality between 2006-2012

	Control group	Treatment group
	Mean *(Standard deviation)*	Mean *(Standard deviation)*
Sales price (1000 SEK)	2100.907	1794.41
	(761.0382)	(643.32)
Square meters	137.162	125.19
	(44.073)	(33.38)
Land area (kvm)	883.1793	714.73
	(555.19)	(507.41)
Assessed (1000 SEK)	1286.16	1039.49
	(458.75)	(366.93)
Population	55660.46	55638.7
	(402.36)	(401.77)
Mean wage (1000 SEK)	246.90	244.78
	(245.18)	(9.89)
	290	
Observations	290	454

In our study we limit our analysis to homes that were sold three years before and after the announcement of the end of the cleaning up process of the Falu mine in late 2008. This ensures that we observe roughly equal periods pre -and post cleanup. Conclusively, we observe data on 744 house sales that occurred between 2006 and 2012 within 3 km from the Falun mine, 454 of which are located within the treatment area.

V. Empirical Methodology

This section provides graphical and basic statistical evidence to support the selected treatment period and the assumption of similar characteristics between the control and treatment group. More evidence is provided in the estimation results in section VI. We then briefly describe the hedonic price model and the econometric identification problems related to it, and finally we present the different model specifications used to determine the potential benefits of cleanup.

A. Graphical and Statistical Evidence

1. Selection of Treatment Period

The Falu projected started in 1992, the same year as the mine closed down and lasted for fifteen years until 2009. Information about the project and contamination of the grounds around the mine has over that period been provided to the inhabitants of Falun by the local municipality and county government. In fact, on an international UN day in October 2012, a lecture was held for the local population of Falun to discuss the measures taken since the beginning of the project to reduce contamination and the positive environmental changes measured since the end of the cleanup.

In our study we choose not to include the whole treatment period but focus on a 3-year period before and after the end of the Falu project to evaluate the rather immediate effect of the end of the cleanup process on people's perception. The change in price contains people's perception and preferences about the positive effects on health, lower acute health risks, decreased stress and concern, increased recreational areas within the remediated area and its surroundings, increased ecosystem services (clean water, waste management, plants) (Rosén, Törneman, Kinell, Söderqvist, Soutukorva, Forssman, Thureson, 2014). These are aspect that could be explored in more detail and included in further research. What is more, our measure of the impact of living close to the mine is based on the populations' assessment of the health risks of living near the mine. It would therefore be interesting to investigate their risk assessment levels, which might not be the same as the assessment that health experts would make of the risks. People's perception of the effect of the end of the cleanup period also depends on their trust to local governments and municipalities, but these are other areas that we do not cover in this study.

2. Definition of Control and Treatment Groups

In figure 5 below we present the contaminated area in Falun, which is the area within the black line. The figure mainly describes the outflow of lead to the community but gives a general overview of how the metals spread from the mine. The area between the black and red line has a lead concentration of 300mg/kg and is rich in heavy metals mostly due to old slag fillings and old slag heaps. The area within the red line has a lead concentration 700 mg/kg or more and is rich in heavy metals due to the old slag fillings and heaps, but it is also very affected by the water leakage from the Falu mine.

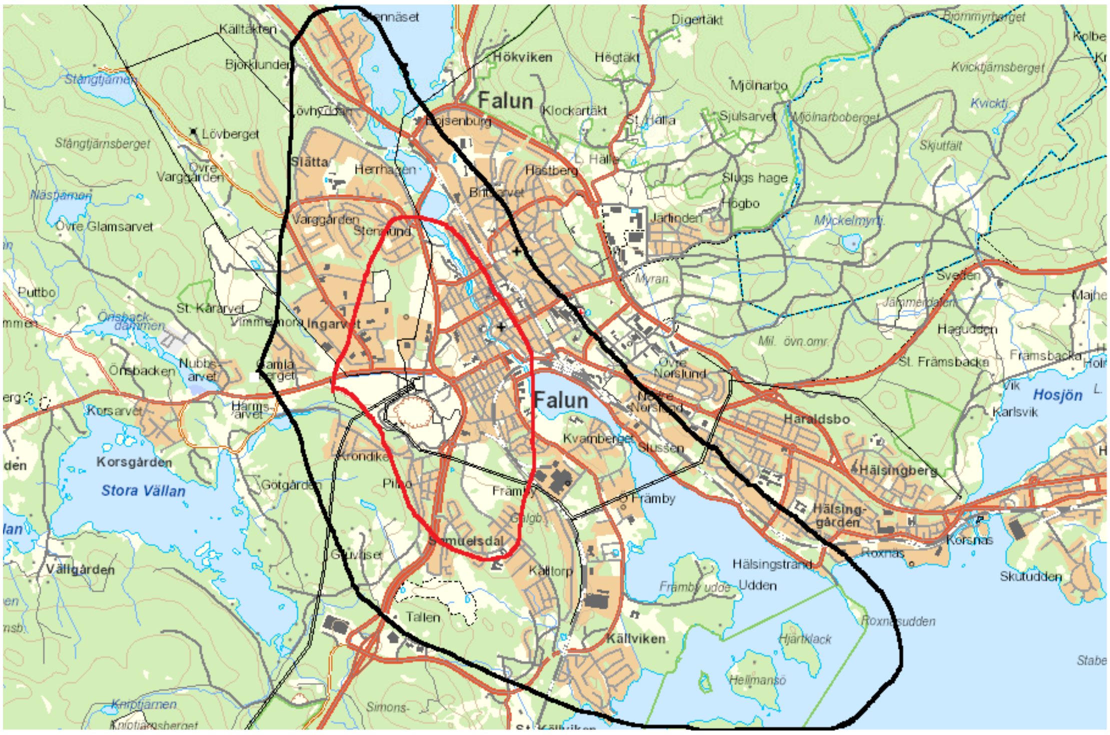

Figure 5. Lead and heavy metal leakage areas (Falu Kommun)

The Swedish EPA provides benchmarks for concentration levels that require special guidelines. The benchmark for the concentration of lead in the ground is 50mg/kg for sensitive use (adults and children can live in the area over a lifetime) and 400 mg/kg for less sensitive use (adults and children can only be in the area during work hours or temporarily). These benchmarks show that the households living on the contaminated grounds are exposed to lead concentrations that exceed the levels recommended by the Swedish EPA. Within areas where the lead concentration is 300mg/kg or more, special measures have to be taken. For the construction of new properties or activities where earth is moved, the ground needs to be replaced or covered so that the lead concentration falls below the benchmark levels of the EPA. Furthermore, the displaced earth requires special treatment to avoid contamination in other locations. The ground in school and playgrounds within the area needs to be frequently analyzed and cleaning routines as well as maintenance of ventilation plants are implemented to diminish the spread of dusts. Surfaces with uncovered ground, for example garden beds, should be removed from school and playground areas. Vegetables that grow underground should not be cultured and the culture of vegetables in general is not recommended, they should be cleaned thoroughly and peeled before being consumed. If the lead concentration is over 400 mg/kg, mushrooms and berries should not be picked. As is shown by figure 5, these guidelines apply to the population living in central Falun.

To further define our treatment and control groups we look at a general overview of how the house prices change in relation to distance to the Falu mine. Figure 6 shows the price gradients of distance to the mine 3 years before the cleanup and 3 years after the cleanup.

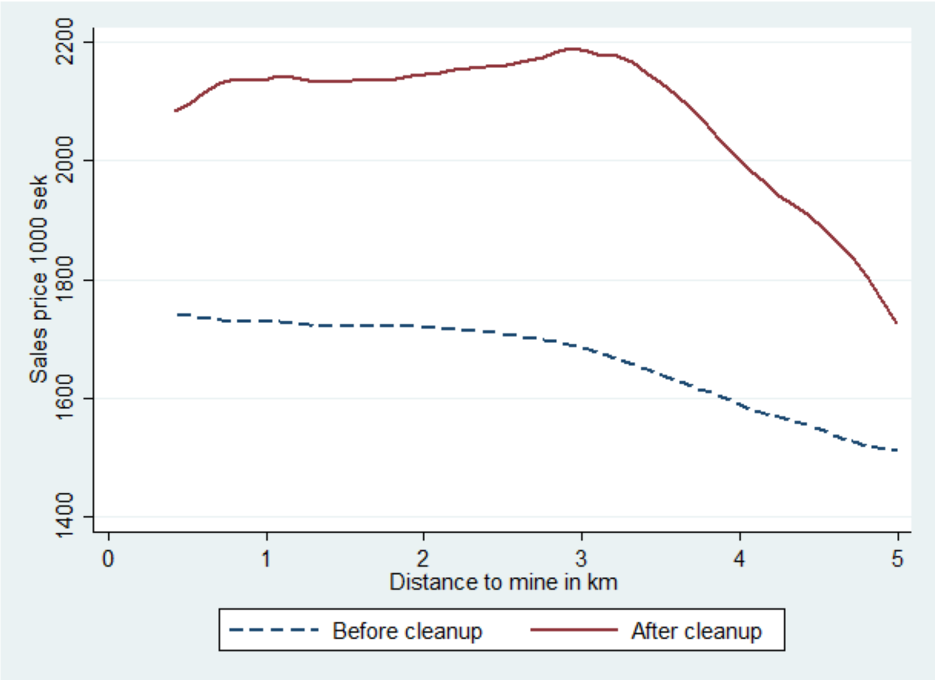

Figure 6 - Gradient of house sales price with distance to mine

Before the cleanup the sales prices are decreasing as the distance to mine increases, as opposed to after the cleanup where prices increase as the distance to mine increase, until the distance to mine reaches 3 km. For both time-periods it is true that the property prices fall dramatically when the distance exceeds 3 kilometers. However, this is not surprising since the mine is situated in the city center. The figure also shows a relative homogeneity in prices for houses sold within the 3-kilometer limit, before the end of remediation. The graphical evidence supports our decision to limit the sample to homes within this 3-kilometer limit. By including properties further away, we would violate the assumption of similarity between the control and treatment group.

Based on figures 5 and 6 we define our treatment and control group. The properties within the red line in figure 5 serve as our treatment group. We are able to precisely define the properties that are located within the redlined area thanks to the individual coordinates provided in the dataset. The control groups are the properties located between the black and red line in figure 5, and also limited by the 3-kilometer cutoff discussed previously.

3. Selection of Variables

The dependent variable in our study is the logarithm sales price of houses. The practical use of the logarithm is to make the interpretation of the regression coefficients very simple. The value of the coefficient represents the percent change in house prices due to the change in the coefficient characteristic. In other words, we evaluate the relative change in the coefficient when the dependent variable is in the log form.

The logarithm is also used to make a non-linear relationship linear. We study the relationship between the sales price and the assessed property value to decide whether to use the log form of the assessed property value. Figure 7 shows the linear relationship between house prices and the taxation value, which rejects the use of the logarithm form of the assessed value in our estimations.

Figure 7. Relationship between Sales price and Taxation value

B. Model Specification

Hedonic price models are widely used to determine demand or monetary value of a non-monetary asset such as the environment. The model is based on the assumption that the utility received by consuming a differentiated good is determined by the different characteristics associated with the good. On that assumption it is possible to decompose and estimate the values of these characteristics. By holding all but the characteristic of interest constant one can determine the implicit value for non-monetary goods. For example, housing prices are determined by a number of different characteristics, one eventually being the proximity to a contaminated mining site (Greenstone and Gallagher 2005). Generally, house prices are negatively correlated with proximity to contaminated sites in papers based on the hedonic pricing approach (Sigman and Stafford 2011). More formally, as described by Greenstone and Gallagher (2005), a differentiated good G can be described as a function of n characteristics g

$$G = (g_1, g_2 \dots g_n) \quad (1)$$

The price P_i of the i^{th}good depends on these characteristics and can be determined by

$$P_i = P(g_1, g_2, \dots g_n) \quad (2)$$

Taking the partial derivative of P with respect to n^{th} characteristic one will obtain the marginal implicit price of that characteristic in the total price of the good. Using the example of price of housing and proximity to a contaminated site, the marginal implicit value should reflect the perceived risk of the contamination on the housing price, hence a negative value. However, it will also reflect other characteristics associated with the contaminated area that affect the house price. Even though many of these characteristics can be controlled for, there is still a high risk of omitted variable bias, both in the cross-section and over time (Linden and Rockoff 2008).

Therefore, using cross-section estimation for the hedonic price model can be problematic due to the unobservable characteristics, which might differ between the areas (Greenstone and Gallagher 2005). Linden and Rockoff (2008) identify this issue when using a hedonic price model to estimate the impact of crime rates on property values. More formally they are estimating the variation in housing prices when a sex offender moves in to a neighborhood. In their specification, relying solely on cross-section estimation would be problematic since variation in property prices might as well be due to unobserved variation in local amenities/disamenities rather than proximity to a sex offender. Instead of relying solely on cross-section variation to compare different neighborhoods, they use a difference-in difference estimation to examine the within-neighborhood variation in property values shortly before and after a sex-offender has moved to the neighborhood. Similarly, we fear that we will suffer the same issues when estimating the effect of the proximity to a contaminated mining site on housing prices using cross-section estimation only, since it might be hard to distinguish between the effect of a cleanup and variation in other unobservable characteristics. We therefore use a differences-in-difference approach similar to Linden and Rockoff (2008) when we estimate the effect of cleanup on property values.

The difference-in-difference method is a panel data model applied to group means when certain groups are exposed to an event (treatment group) that others are not exposed to (control group). This approach is well suited to estimate the effect of a sudden change in the economic environment. Following the example from Angrist and Kreuger (1999), the difference-in-difference method can be applied as follows; let Y_{0i} be the price of a property i in the absence of remediation and Y_{1i} the price of a property i when it is affected by a remediation. The average price for a property in area c at time t is $E[Y_{0i}|c,t]$, with no remediation, and $E[Y_{1i}|c,t]$ if a remediation happens. The method then identifies the causal effect by restricting the conditional mean function $E[Y_{0i}|c,t]$. Suppose that

$$E[Y_{0i}|c,t] = \beta_t + \emptyset_c \quad (3)$$

which means that in the absence of remediation the average property price can be expressed as a year effect, β_t, and an area specific effect fixed over time, $\emptyset_c$. The effect of the remediation is obtained by adding a constant to $E[Y_{0i}|c,t]$, so that

$$E[Y_{1i}|c,t] = E[Y_{0i}|c,t] + \delta \quad (4)$$

This can then be rewritten as

$$Y_i = \beta_t + \emptyset_c + \delta M_i + \varepsilon_i \quad (5)$$

where $E[\varepsilon_i|c,t] = 0$ and M_i is a dummy variable that equals to 1 if property i was exposed to the remediation. In our case, differentiating between property prices across the treatment and control group and across years is

$$\{E[Y_i|c = treatmentgroup\,, t > 2009] - E[Y_i|c = controlgroup\,, t > 2009]\}$$
$$-\{E[Y_i|c = treatmentgroup\,, t < 2009] - E[Y_i|c = controlgroup\,, t < 2009]\}$$
$$= \delta \quad (6)$$

This implies that the Difference-in-Difference model can be computed in a regression of micro data for neighborhoods and years.

The coefficients in our regression framework consist of a dummy variable, $post_{it}$, indicating whether the sale took place after the remediation, a dummy variable, $treatment_{ijt}$, indicating if the property is in the treatment group and a dummy variable, $post_{it} * treatment_{ijt}$, for the interaction between observations on houses sold after 2009 ($post$) and properties located in the treatment group ($treatment$). We also add a vector of individual characteristics X_i and area and year specific fixed effects α_{tj}, and finally a random error term ε_{ijt}. The model is then

$$\ln(p_{ijt}) = \alpha_{tj} + \beta X_i + \theta_2 treatment_{ijt} + \theta_3 post_{ijt} + \theta_4 (post_{it} * treatment_{ijt}) + \varepsilon_{ijt} \quad (7)$$

An issue for our analysis is the very limited number of house characteristics only including living area, total area of the property or assessed tax value of the property. The lack of explanatory variables would generally be a big limitation for the analysis, however, as mentioned in section 2, the assessed tax value accounts for a number of different housing characteristics, including living area and total property area both for the individual properties and for the neighboring area. Relying on the assumption that the assessed tax value can be used as an instrument for many of the missing characteristics we proceed with a prediction of the value of cleanup. We use 2 different variations of equation 7 as our baseline specifications. First we use the assessed tax value as an instrument for all housing characteristics. This means that in equation 7 the X_i is the assessed taxed value for each individual property. Including the assessed tax value might introduce a risk of conservative estimates since it captures some of the area specific fixed effects, α_j, but we choose to include it in the specification to minimize the risk of omitted variable bias. In the second baseline, specification X_i consists of the individual size of the house, $square\ meter_i$, and the individual size of the property, $land\ area_i$. As in the first specification, we control for both the area and time fixed effects α_{jt}.

Like any other identification strategy, the difference in difference model is not guaranteed to estimate the causal effect of treatment. The key identification assumption is that the treatment effect is zero in the case of no treatment (Angrist and

Kreuger 1999). For example, one could imagine that the property prices were to evolve differently for the control and treatment group even without a shock such as the remediation. A way to test for this is to compare the price trends before the treatment. For the model to be viable we should not detect a difference in price trends between the control and treatment group pre-remediation. This is tested for and presented in section VI-A. We show that the price trends between the control and treatment group are similar in a graph, and we also test for specific year trends in a regression framework. We interact the property prices for the remediated area with dummies for the years before the end of cleanup to see if there is a significant difference in price trend between the remediated and non-remediated areas.

VI. Estimation Results

We will now present the results from our hedonic price model and discuss the effect of the cleanup on residential property prices in Falun.

A. Differences in Characteristics of Houses close to the Mine

Our estimation relies on the similarity of houses lying within the remediated area and those lying outside of it. To check for this similarity we look at the price trends over the years before the cleanup for the treatment group and the control group. If the estimates for the year dummies are significant, this would mean that the difference in price between houses in the contaminated area and the other houses over time is significant, which would invalidate the use of our model.

We study this difference in Table 2 where we interact the property prices for the remediated area with dummies for the years before the end of cleanup.

Table 2. Year dummy regression

VARIABLE	Ln (Price)
remediated	-0.128***
	(0.0416)
year = 2006	-0.379
	(0.391)
year = 2007	-0.270
	(0.391)
year = 2008	-0.310
	(0.391)
Constant	7.741***
	(0.389)
Observations	374
R-squared	0.038

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

As we can see from the table above, the estimates for years 2006, 2007, 2008 are statistically insignificant, which points to the fact that we find no difference in price trends between houses in the treatment group and houses in the control group before the end of the cleanup.

To illustrate the results we provide graphical evidence in figure 8 below. The red graph shows the price trend of houses in the control group and the blue graph shows the price trend for the treatment group between 2006 and 2014. Our entire period of study is shown within the two thick red lines. Between 2006 and 2009, the period before the end of the cleanup, the trend in prices for the treatment and control groups are similar. This confirms that there is no significant difference in price trends between the two groups and allows us to continue with our difference-in-difference model in the following section.

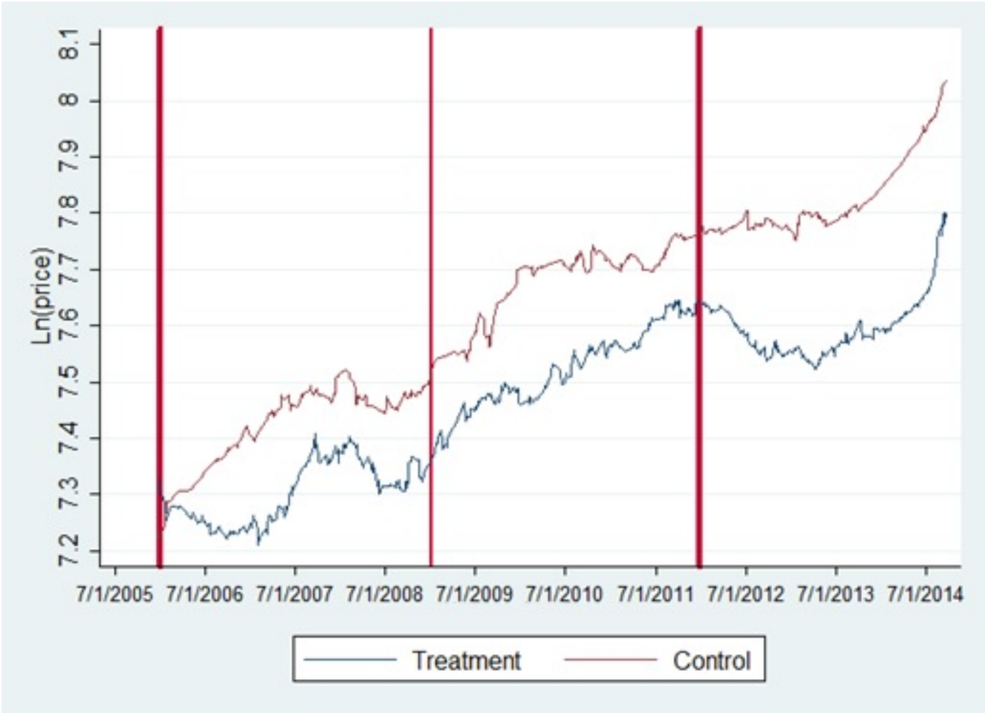

Figure 8. Price trend over year for remediated and non-remediated areas

Looking at the prices after 2012, it seems like the price gap between the treatment and control group is starting to increase. This might indicate that the remediation only had a short-run effect on the property prices in the directly affected area, or that the treatment effect is just a coincidental cyclical effect. It can also be the case that the houses sold in the treatment group are less valuable in terms of the observable characteristics. This is controlled for in the specifications presented in the next section, but it is not visible in figure 8 since it only accounts for the actual sales prices and does not control for house characteristics. This potential issue is further evaluated in table 6 in section VII.

B. Impact of the End of Cleanup on House Prices

With the assertion that there is no difference in price trends over time between the treatment and control group, we continue our analysis by estimating the interaction effect between the house prices in the remediated and the contaminated area after the end of the cleanup in table 3.

Columns 1 and 2 present the estimates over a period of 3 years before and after the end of the cleanup. The coefficients in column 1 show the results from estimating equation 7, controlling for year and area fixed effects and the houses' assessed value as an explanatory variable. Houses in the remediated area have increased by approximately 6.9 percent since the end of the cleanup compared to houses outside the area (post_treatment), the result being significant at a 1-percent level.

In column 2 we present the result from estimating equation 7 again, still using the year and area fixed effect but using the house size and the property size as control variables instead. Houses in the remediated area have now increased by on average 6.3 percent more than other houses after the end of the cleanup. The result is statistically significant at a 5-percent level and very similar to when we use the assessed value as a control variable.

The increase in price in the remediated area reinforces our hypothesis that the sanitation of contaminated sites around the Falu mine makes the area more appealing, which is reflected in the increase in property prices. It is worth noticing that the treatment effects obtained in column 1 and 2 are similar, which implies that the two model specifications provide similar estimates and that our results are robust.

Table 3. Interaction Effect of Price on Remediated Area after Cleanup

Dependent variable:	3- year period		2- year period	
Ln(price)	(Assessed value)	(Area)	(Assessed value)	(Area)
$post * treatment$	0.0691***	0.0626**	0.0681**	0.0800**
	(0.0179)	(0.0187)	(0.0236)	(0.0198)
$treatment$	0.00539	0.0988	-0.00979	-0.111***
	(0.0154)	(0.116)	(0.0127)	(0.0110)
$post$	-0.0806***	-0.0408	0.269***	0.178***
	(0.00635)	(0.0400)	(0.0341)	(0.0193)
$square\ meter$		0.00476***		0.00561***
		(0.000240)		(0.000240)
$land\ area$		9.77e-05***		6.50e-05
		(1.78e-05)		(3.55e-05)
$assessed\ tax\ value$	0.000749***		0.000704***	
	(6.66e-05)		(7.03e-05)	
$constant$	6.650***	6.923***	6.549***	6.661***
	(0.0830)	(0.0240)	(0.105)	(0.0562)
Year fixed effects	Yes	Yes	Yes	Yes
Neighborhood fixed effects	Yes	Yes	Yes	Yes
Observations	744	744	503	503
R-squared	0.554	0.499	0.545	0.387

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

We repeat the same three steps as above but looking at house price difference over a period of 2 years before and after the end of the cleanup and present the results in columns 3 and 4 of table 3.

The estimate in column 3 that controls for the assessed property value shows that the trend is similar when looking at a 2-year period and a 3-year period pre- and post cleanup; there is a 6.8 percent increase in prices after the end of the cleanup for houses in the remediated area compared to houses outside the area. This difference is also statistically significant at a 5-percent level.

The effect is larger in column 4 where we control for the house size and property size over a 2-year period instead of the assessed property value. In fact, the increase in price for houses in the remediated area is of 8-percent compared to houses outside the contaminated area.

Using only house and property size as control variables might overestimate and produce biased parameters since many characteristics that explain house prices are left out. As we discussed in the data section, the assessed property value takes into account a large number of house and property characteristics, such as the house size and property size, the age and proximity to water of the property amongst others. The assessed property value variable thus controls for house and property size but includes other controls as well. We therefore choose to rely on the estimates from this specification rather than the specification with only house and property size when we perform a cost and benefit analysis in section VIII below.

The results from Table 3 show that after the end of the cleanup, the houses located in the remediated areas close to the mine increased by 6.9 percent more than houses in non-remediated areas three years after the end of the cleanup, this difference being statistically significant. We are therefore able to conclude that after the sanitation of the grounds in central Falun, the average price has increased more on average for the houses directly affect by the remediation. These findings might indicate that homeowners in Falun are willing to pay more to live in a remediated area, which is shown by the increase in property prices.

VII. Robustness Check

We now apply the same estimation as in equation 7 but to different time periods and with different end of remediation dates to check for unobserved events or trends that might have affected our results.

A. Unobserved Explanatory Events

In table 4 we present another simple sensitivity test for our specification. The first two columns represent the specifications obtained in table 3 with the original treatment period. The two latter columns represent the original specifications but with an extended four-month treatment period. By extending the treatment period we are able to check for unobserved events taking place close to the date of the end of treatment that might affect the housing prices. The increase in price that we find in table 3 might be due to other events, other than the end of the treatment period, that temporarily affect house prices and would therefore produce biased estimates.

Table 4. Estimation of the Effect with an Extended Treatment Period

Dependent variable:	Original Treatment period		Extended Treatment period	
Ln(price)	(Assessed value)	(Area)	(Assessed value)	(Area)
$post * treatment$	0.0691***	0.0626**	0.0618**	0. 0525
	(0.0179)	(0.0187)	(0.0240)	(0. 0238)
$treatment$	0.00539	0.0988	0.0092	-0.1505**
	(0.0154)	(0.116)	(0.0161)	(0.0578)
$post$	-0.0806***	-0.0408	0.0304	0. 0451
	(0.00635)	(0.0400)	(0.0162)	(0. 0216)
$square\ meter$		0.00476***		0. 0047***
		(0.000240)		(0.0002)
$land\ area$		9.77e-05***		9.72e-05**
		(1.78e-05)		(1.81e-05)
$assessed\ tax\ value$	0.000749***		0.0007***	
	(6.66e-05)		(6.7e-05)	
$constant$	6.650***	6.923***	6.595***	6.892***
	(0.0830)	(0.0240)	(0.0752)	(.0253)
Year fixed effects	Yes	Yes	Yes	Yes
Neighborhood fixed effects	Yes	Yes	Yes	Yes
Observations	744	744	744	744
R-squared	0.554	0.499	0.554	0.499

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

The results from table 4 show that our estimates do not change much at all when extending the treatment period. The treatment effect is very similar between the two treatment periods, which indicates that the increase in price after remediation is consistent and that our estimates are not biased.

An alternative interpretation could be that there has been an increase in the amount of people that move in to Falun and that, as a result, the prices in the central areas increase more. We control for this in figure 9 by looking at the house market situation in Falun before and after the end of the cleanup. The house market in Falun over the studied period is balanced, which shows that there is no supply deficit in housing that could have pulled the house prices upwards. We also check the amount of houses sold within the remediated area in 2008 compared to 2009. 136 houses were sold in 2008 and 126 in 2009, which shows that the amount of houses sold is very similar before and after the end of the cleanup.

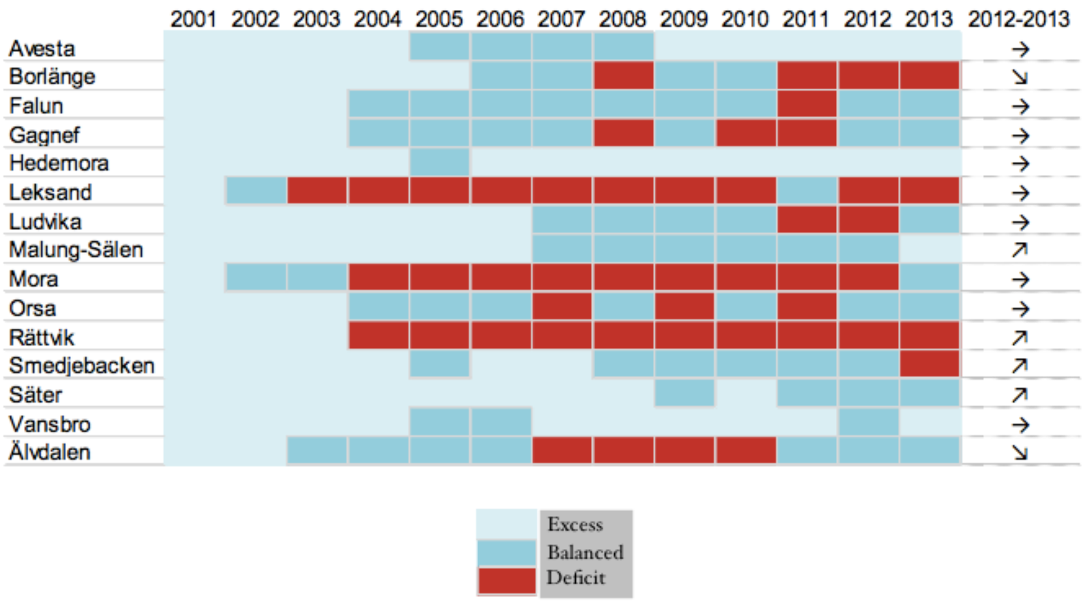

Figure 9. Housing market situation in Dalarna, ***Länsstyrelsen Dalarna Report 2013:18***

B. Price Trends of Treatment and Control Groups Pre-treatment

We extend the analysis of pre-treatment differences in price trends for the control and treatment group from figure 8 and table 2. Table 5 shows the estimates from the standard difference-in-difference model (equation 7), but with "false" cleanup-dates to check for interaction effects on prices between the two groups using different dates. The results in column 1 and 2 are obtained using the false date of cleanup 31/12 2006, while Column 3 and 4 uses the false date of cleanup 31/12 2007. All 4 columns present results using houses prices from a pre- and post remediation period of 1 year. The obtained coefficient for the treatment effect is statistically insignificant for all 4 specifications. Hence, we cannot reject that the treatment effect is statistically different from 0 at any common significance level. These results further strengthen our estimates in section VI.A: there is no difference in price-trends between the treatment and control group before the end of the cleanup in 2009.

Table 5. Robustness check with "false" end of cleanup dates

	Pre and post remediation period equal to 1 year			
Dependent variable: Ln(price)	01/2006-01/2008		01/2007-01/2009	
	(Assessed value)	(Area)	(Assessed value)	(Area)
post ∗ treatment	-0.0698	-0.126	-0.0310	-0.0583
	(0.0700)	(0.0819)	(0.0673)	(0.0724)
treatment	0.110**	0.227	0.0401	0.157
	(0.0536)	(0.158)	(0.0495)	(0.203)
post	0.271**	0.294*	0.0427	0.240**
	(0.136)	(0.151)	(0.114)	(0.120)
square meter		0.00497***		0.00509***
		(0.000574)		(0.000578)
land area		9.14e-05		0.000143***
		(5.61e-05)		(4.79e-05)
assessed tax value	0.000921***		0.000921***	
	(5.50e-05)		(5.53e-05)	
constant	6.273***	6.589***	6.467***	6.696***
	(0.103)	(0.138)	(0.0816)	(0.110)
Year fixed effects	Yes	Yes	Yes	Yes
Neighborhood fixed effects	Yes	Yes	Yes	Yes
Observations	239	239	274	274
R-squared	0.563	0.520	0.531	0.545

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

C. Checking for Long-Term Effects

In figure 8 in section VI we detected an increasing gap in prices between the treatment and control group during the years 2012 and 2014. This could indicate that the remediation only had a short-run effect on housing prices, or that the treatment had spill-over effects on areas that we didn't account for. A more serious issue would be if it indicates that the price change is cyclical and that the increase for the treatment group will be mitigated by a counterfactual increase for the control group in the following years. To investigate this, we use the same difference-in-difference model as previous (equation 7), but we change the time period. We now look at the time period following our studied period. The pre-treatment period is 2012-01-01 to 2013-06-01 and the post-treatment period is 2013-06-01 to 2014-09-19. The results are presented in table 6.

Table 6. Regression showing Long Term Effects

Dependent variable: Ln(price)	2012-2014 (Assessed value)	2012-2014 (Area)
$post * treatment$	-0.0276	-0.0216
	(0.0374)	(0.0510)
$treatment$	-0.0183	0.0544
	(0.0389)	(0.0338)
$post$	-0.0781**	0.119
	(0.0201)	(0.0667)
$square\ meter$		0.00490***
		(0.000294)
$land\ area$		9.40e-05**
		(2.91e-05)
$assessed\ tax\ value$	0.000632***	
	(5.31e-05)	
$constant$	6.785***	7.010***
	(0.0962)	(0.0780)
Year fixed effects	Yes	Yes
Neighborhood fixed effects	Yes	Yes
Observations	356	356
R-squared	0.637	0.555

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

We find no significant treatment effect in either of the two specifications. Hence, controlling for the observable housing characteristics, it seems like there is no difference in price trends between the control and treatment group after our period of study. Since our data is limited to 2014-09-19 we cannot further investigate the long-run effect. But these results could indicate that, during the 3-year period after the remediation, housing prices increased for the treatment group compared to the control as an effect of the remediation. After the 3-year increase for the treatment group, the price trends become parallel between the control and the treatment group and prices increases.

VIII. Cost and Benefit Analysis of Remediation

In this section we use the obtained estimates from the previous section to calculate the benefits of cleaning up mine waste by performing a cost and benefit analysis.

A cost and benefit analysis is often used to put a monetary value on intangible assets, like the costs and benefits of living in a clean environment. The households' preferences are revealed by what they purchase under different circumstances (Samuelson, 1938), in our study the populations' valuations about living in a clean environment are estimated. The results found in section VII show that cleaning up contaminated areas around the Falun mine has a statistically positive and significant effect on the sales prices of houses situated in close vicinity to the mine. This increase indicates that households have a willingness to trade off higher housing prices to decrease contamination risks. The welfare cost of living in polluted areas for the population in Falun can then be used to make optimal policy decisions.

To calculate the benefits from remediation we start by looking at the mean sales price of houses in Falun before the end of the cleanup in 2009 and within the treatment area, which is SEK 1,794,410 and the average land area for the houses located in the treatment area, which 714.7313 square meters. We then calculate the average price per square meter of land area:

1,794,410/714.7313= 2510.61 SEK

The results from our estimation in table 3 show that the estimate for the interaction effect of houses prices in the remediated area after the cleanup corresponds to a 6.9% increase in price.

$$Ln(Price) = 6.650 - 0.00539 * Treatment + 0.0691 * Post\_Treatment - 0.0806 * Post$$

The profit for each square meter of land area after the increase in price in the remediated area post-cleanup is then:

2510.61 *0.0691=173.48 SEK

We apply this profit on the total land area of the properties in Falun located in the remediated area, which is 580,610 square meters. The total profit of the increase in price in the remediated area is:

580,610*173.48 = 100,725,965 SEK

The total benefit for the city of Falun of remediating mining areas is SEK 100,725,965. However, in our study we only measure the benefits of the cleanup on sold houses between 2006 and 2012. To have a more accurate idea of what the total benefits are it would be necessary to also include commercial and industrial properties, many of which are located close to the mine, to assess the welfare cost of working near the mine. It would also be necessary to apply the increase in price on all houses owned in Falun located in the remediated area, rather than only on those that got sold over the observed period. However, due to a lack of resources, we approximate the benefits on houses sold over our observed period only.

The Swedish EPA declares that the government, in accordance with Stora, allotted SEK 98 million to the Faluproject between 2004 and 2009.

$$Totalt\ cost\ to\ government = 98{,}000{,}000 - 100{,}725{,}965 = -2{,}725{,}965\ SEK$$

With the estimations done in our model, the Swedish government has made a profit of SEK 2,725,965 from remediating the heavily contaminated area near the Falu mine. This figure may be undervalued since we do not include all properties and further research is necessary to include more properties in Falun and other positive aspects that follow from living in a cleaner environment.

X. Conclusion

We use a difference-in-difference model to evaluate the effect of the end of cleanup in and around the World Heritage Site of the Falu mine. Data is collected on the location of the mine and on sales prices of residential properties located within the remediated area three years before and after the end of the Falu project. We then estimate the difference in sales price between houses within the remediated area and those located further away. We find that after the end of the cleanup in 2008 the value of houses located in the remediated area rose by 6.9 percent more than in other areas. Most of the existing literature in Sweden about sanitation of contaminated areas focuses on the environmental and health aspects of the issue, our research contributes to the literature by offering an economical perspective on the effects of sanitation in a populated area, which in general should be included in policy decisions and environmental work.

The estimate that we found suggests that the population in Falun have a dislike for living in contaminated areas. We calculated that the total benefit for the city of Falun for remediating mining areas is SEK 100,725,965. This result indicates that the population of Falun is willing to pay a higher price for policies that assure a cleaner environment and lowered health risks.

It is important to once again mention that our results are estimated using a limited amount of controls. Future research should include more controls to enable further validation of the hypotheses that the sanitation of Falu mine had a significant positive impact on the housing prices. What is more, due to a lack of time and resources we were not able to include all properties in Falun (properties that were not sold during the observed period), commercial and industrial properties. Therefore it is possible, based on the results from our difference-in-difference estimation, that the estimate in the cost-benefit analysis is conservative.

In this study we found that the benefits from remediating around the Falun mine were greater than the costs. However, we do not investigate if these results can be extrapolated to other mines in Sweden. Despite the large amounts of waste and the negative impact that it has on the environment, there is a lack of regulations and long-term strategy as to the management of the mining waste. The Swedish National Audit

Organization released a report in December 2015 drawing attention to the need of technical guidance and management of mining waste in Sweden. Deciding which party to hold liable for funding the remediation and how the funding should be optimally allocated is an area which is out of the scope of this paper, but highly relevant for policy implications. Environmental funds, where collateral is collected from the operating mining companies to finance future remediation and future environmental costs, could be a potential channel for Sweden to transfer the costs from the public to the polluting industries.

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