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Geographic Constraints and Housing Supply in Sweden

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Abstract

Motivated by the debate on the role of supply side constraints in hampering new housing construction in the Swedish housing market, this study replicates the methodology of Saiz (2010) to investigate the role played by geographic constraints in determining housing supply elasticities. A sample of 109 municipalities is analyzed over the period 1993-2003. Using geographic information system (GIS) techniques a measure of undevelopable land, defined as land corresponding to water bodies or terrain with an incline greater than 15 percent, is created. Instrumenting for housing supply using Bartik instruments, immigration shocks and average January temperatures, the average housing supply elasticity is estimated using 2SLS. The role that undevelopable land has in determining the housing supply elasticity is then explored. Results indicate a very low average elasticity of housing supply. Geographic constraints meanwhile cannot be shown to explain the housing supply elasticity.

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1 INTRODUCTION

To the extent that the supply of housing is responsive to fluctuations in the demand for housing, common demand shocks such as population growth and immigration need not translate into higher house prices if adjustment mainly occurs on the quantity side. From this perspective, differences in price growth between regions can be explained by local heterogeneity in supply that makes supply less responsive or elastic in some markets. In this context, an understanding of the determinants of local housing supply elasticities becomes crucial. While research has mainly focused on the role of regulation as a determinant of the supply elasticity, natural constraints imposed by geography have received less attention. Nevertheless, geography can constrain the supply of housing in an indisputable way. Moreover, in contrast to regulation that is likely endogenous to many housing market variables, geography is arguably exogenous, facilitating empirical estimation. The aim of this thesis is to investigate the role of geography as a determinant of housing supply elasticities in Sweden.

Supply side factors have dominated the debate in Sweden on the causes of the substantial house price growth seen over the last decades. For the period 1993-2015 nominal house prices rose by 374 percent[1] with substantial variation across the 290 municipalities of the country. Paralleling this price growth is a surprisingly modest increase in the housing supply. In 2003, 100 municipalities reported having a housing shortage.[2] In 2016, the corresponding figure was 183. Various aspects of the supply side have been assessed from a policy perspective in terms of the extent to which they constrain new construction. Two recognized constraints include stringent regulation and lack of competition in the construction sector. The role of geography is far less explored.

Nevertheless, an interesting feature of the various local housing markets in Sweden is a varying topography. Water bodies such as rivers and lakes, proximity to the Baltic and North seas, and rugged terrain in the north generate substantial regional variation. As a case in point, the capital city Stockholm is characterized by various geographic features that constrain construction; in the west the lake Mälaren, to the east the Baltic sea, and various elevated areas such as in Liljeholmen. By contrast the inland municipality Linköping is subject to nearly none of the geographic constraints that Stockholm faces. Incidentally, while the former has experienced a low level of price growth, the latter has experienced a much higher price growth.

A seminal contribution with regards to the role of geography as a determinant of the housing supply elasticity was made by Saiz (2010). Saiz found that the percentage of undevelopable land, due to the presence of water bodies and steep-slope zones with an incline greater than 15 percent, was an important determinant of local supply elasticities in the US. Since its publication, the paper has received much attention partly due the tractability of the elasticity estimates— the arguably exogenous property of the

[1] As measured by the Real Estate Price Index for one and two dwelling buildings.

[2] Every year Sweden's National Board of Housing, Building and Planning (in Swedish: Boverket) conducts The Housing Market Survey (in Swedish: Bostadsmarknadsenkäten). One of the questions of the survey asks the municipality to describe if there is a "shortage", "balance" or "surplus" of housing in the municipality.

elasticities have rendered them useful in other fields of research and most notably research on housing wealth effects where they have served as instruments.[3]

Motivated by the relative gap in the literature on the role of geography and the quest for understanding the supply side factors that have led to the absence of a supply side response in Sweden, I investigate the role of geography as a supply side constraint by replicating the methodology of Saiz (2010). In this thesis I formalize the relationship between house prices and housing supply for a sample of 109 Swedish municipalities for the period 1993-2003, providing an estimate of the average housing supply elasticity. Using geographic information systems (GIS) techniques, I assess the importance of geography in explaining the observed housing supply elasticity by constructing a measure of undevelopable land, defined as the fraction of land covered by water bodies or steep-slope terrain[4] within a circle of 5 km radius, with the centroid defined as the central city of each of the 109 municipalities. The constructed measure indicates considerable variation in the amount of undevelopable land across municipalities.

The empirical design explores demand shifters that can be used as instruments for housing supply. Exploiting Bartik instruments, immigration shocks, and average January temperatures, I use 2SLS to estimate an average housing supply elasticity and explore the extent to which undevelopable land explains the observed elasticity closely following the methodology of Saiz (2010).

I find an average housing supply elasticity of approximately 0.0784—an order of magnitude lower than what has been found in the US and also in comparison to the Swedish elasticity estimate of Caldera-Sanchez and Johansson (2013), but similar to a recent policy paper by Ho (2015), and in line with the informal notion of an inelastic housing supply in Sweden (Englund, 2011). However, in contrast to Saiz (2010), geography is not found to be a determinant of the housing supply elasticity. Against the backdrop of the institutional setting in Sweden, I suggest possible reasons for this.

The scope of this study is limited in three ways. First, I restrict the sample of municipalities to only include those that are relatively urbanized, the rationale being that land availability is more likely to act as a constraint on housing supply in urban markets. This corresponds to 109 out of 290 municipalities. Of these, 53 reported a housing shortage in 2003. However, to assess the sensitivity of the estimated parameter I also use a different classification rule as a robustness check. Second, I limit the time frame to the decade 1993-2003, a choice that is partly driven by data availability. As such the supply elasticity found is not truly long-term and does not capture the most recent developments in the Swedish housing market. Nevertheless, although at the possible expense of external validity, the choice strengthens internal validity.[5] Third, while Saiz (2010) also assesses the role of regulation, I refrain from doing so in this study. The main reason for this is that there is to date and to the best of my knowledge no comprehensive regulatory index in Sweden comparable to the Wharton Residential Urban Land Regulation Index (Gyourko, Saiz, and Summers, 2008) in the US used by

[3] See for instance research by Mian and Sufi and their book House of Debt.
[4] Steep-slope terrain corresponds to terrain with a slope of above 15 percent as in Saiz (2010). Such an incline constrains construction.
[5] This is discussed in more detail in section five.

Saiz (2010). If future research will see the construction of such an index, the current framework lends itself to an analysis of regulation as well.

This thesis relates to the current field of research as follows. It is first and foremost a replication of parts of Saiz (2010) to the Swedish context. It resembles that of Oikarinen, Peltola, and Valtonen (2014) in the sense that it extends the analysis of geography and housing supply elasticities to a setting vastly different from the American one; in my case Sweden, in their case Finland. Furthermore, while Wilhelmsson (2008) suggests that the availability of undeveloped land may explain the faster price responses observed in some regions in Sweden, I empirically test for the importance of land availability. The objective of Ho (2015); to estimate housing supply elasticities and empirically analyze the effect of the supply elasticity and developable land on price growth in Sweden, comes the closest to the objective of this study, although the empirical methods differ. Ho (2015) points out that for empirical analysis one should ideally have a measure of developable land as constructed by Saiz (2010) in order to assess natural land constraints. In the absence of such a measure in Sweden the author uses population density and land development as proxies. In this study I construct such a measure.

Hence, three contributions are made with this study. First, this is the first study to empirically estimate the role of geography in explaining housing supply elasticities in Sweden using the framework of Saiz (2010). Second, the measure of undevelopable land constructed can, to the extent that it is exogenous to local economic conditions, be useful in its own right in other contexts. Third, the baseline econometric model estimated and the identified instruments can be extended to allow for an analysis of regulation.

The thesis is structured as follows. Section two provides a brief background to the Swedish housing market during the period 1993-2003 and some of the institutional features. An overview of related research is presented in section three, with a particular focus on Saiz (2010). Section four is concerned with the construction of a measure of undevelopable land in Sweden. Section five presents the empirical design. Data and summary statistics are provided in the following section. Section seven presents the results. Finally, a discussion and conclusion is provided in section eight.

2 BACKGROUND

The last two decades have been characterized by sharp and sustained increases in house prices in Sweden. This upward trend has not seen a corresponding expansion of the housing stock. In fact, the level of new construction has remained at a low level since the financial crisis in the beginning of the 1990s, both from a historical perspective and in comparison with other countries (Emanuelsson, 2015). Understanding why housing supply was restrained during the period 1993-2003, and still is so today, is of immediate relevance in order to counteract the shortages that exist in many of the country's municipalities. This section starts by providing a glimpse of the housing market during 1993-2003 in figures. Next, a brief discussion of supply side constraints recognized as factors hindering new construction is given. Being characteristics of the institutional framework, these constraints are still very relevant today. Finally, the notion of geographic constraints, a largely unexplored supply side constraint in the Swedish context, is added to this supply side story.

Rising prices and a stagnant supply…

A descriptive analysis of the housing market in 1993-2003 has to be made against the backdrop of the severe economic downturn that hit Sweden in 1990. Between 1991 and 1993 GDP fell by over five percent. At the same time the "tax reform of the century" in 1991 was partly financed by VAT increases in the construction sector, and the reduction of interest rate subsidies for new owner-occupied houses affected the financing of new construction (Agell, Englund and Södersten, 1996; Lind, 2002; Lind, 2003). As a result, new construction was virtually non-existing in the beginning of the 1990s. Nevertheless, from 1996 onwards prices rose at a steady pace. As can be seen in Figure 1, over the entire period real house prices increased by a little over 60 percent. Although house price growth was paralleled by a growth in construction costs, the growth of the former was much higher, suggesting that more expensive construction on its own cannot explain the increase in house prices.[6] Paralleling this was an exceptionally low level of new construction. While only 20 municipalities reported a housing shortage in 1993-1995 (Lind, 2003), by 2003, this number had increased to 100.[7]

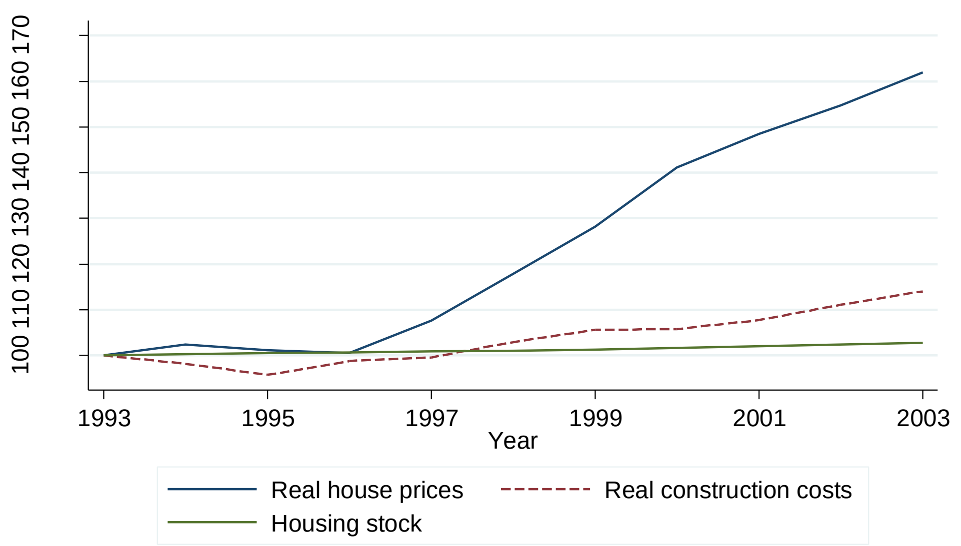
During this period, there was also considerable regional variation in price appreciation. The relative price index of regions displayed an increasing divergence after 1995 (Englund, 2011). Figure 2 highlights the price appreciation of the 109 municipalities of this study, according to their percentiles. The figure illustrates that the metropolitan regions of Stockholm, Göteborg, and Malmö experienced particularly high levels of price growth. This variation across municipalities suggests that local factors

[6] This reflects the profitability condition of construction companies. If construction costs are above house prices, i.e. the ratio of house prices to construction costs is less than one (this is also referred to as Tobin's Q, see Tobin (1969)), it is not profitable to produce housing. In fact, Berg and Berger (2005), find results that indicate a high correlation between the Q-ratio and the number of buildings for the period 1993-2003.
[7] Sweden's National Board of Housing, Building and Planning (2003).

and possibly different supply side conditions play a role in explaining the cross-sectional variation in price appreciation.

FIGURE 1

Real House Price, Construction Cost and Housing Stock Growth, 1993-2003

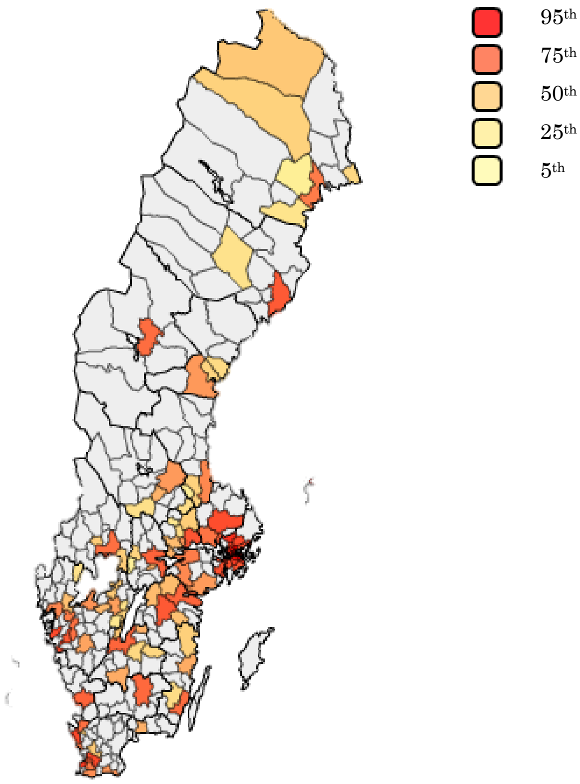


Notes: Real house prices are defined as Statistics Sweden's Real Estate Price Index deflated by the CPI. Real construction costs are defined as Statistics Sweden's Factor Price Index for buildings deflated by the PPI. The housing stock is defined as the number of one- or two-dwelling buildings.

Source: Statistics Sweden and own calculations.

FIGURE 2

Nominal House Price Growth, 1993-2003



Notes: House prices refer to one- and two- dwellings buildings. Municipalities in grey are not part of the sample of this study. Sample of 109 municipalities.

Source: Statistikatlas (Statistics Sweden) and own calculations.

All in all, the figures suggest three findings that provide initial motivation for further studies. First, construction cost growth alone cannot explain the house price growth and this directs attention to the potential role played by other supply side factors. Second, low levels of new construction and strong price growth give a first qualitative indication of a low elasticity of housing supply. Finally, the large variation across municipalities suggests that local supply may be heterogeneous. It also indicates the suitability of an econometric model that exploits cross-sectional variation.

... as causes of institutions and competition...

Several explanations have been provided for the lack of new construction in Sweden over the last decades. Here I provide an overview of two factors, closely following the explanatory model proposed by Lind (2003),[8] which explicitly focuses on the period 1995-2001. Hüfner and Lundsgaard (2007) make similar findings. Lind (2003) identifies three supply side factors that limited new construction. First, land owners[9] may be reluctant to sell to developers. If the land owner is also the developer, there may be various incentive compatibility constraints that reduce the willingness of the owner to develop the land. One such incentive constraint arises if the house price is viewed as an option. By waiting to build, a higher selling price may be obtained.[10]

Second, the municipal planning process has often been described as prolonged and unpredictable, with the possibility of various interest groups influencing or controlling the outcome to their own advantage, in accordance with what is known as the "homevoter hypothesis".[11] With large possibilities to appeal, the outcome and length of the planning process can vary substantially. From the perspective of construction companies, this increases the risks of the building process, reducing incentives for new entrants to enter the industry. This in turn has an impact on the level of competition. Lack of competition in the construction sector is also the third factor in Lind (2003). Important to note, aspects of the regulatory framework, such as the system of rent regulation, can act to further constrain the supply of housing, although this is not discussed further here.

...and geography?

It is intuitive that geographic constraints restrict the supply of land available for an expansion of the housing stock. For example, markets located by the coast can only expand in one direction (SOU 2015:48). Out of the sample of 109 municipalities, 31 municipalities are coastal ones. For the country as a whole however, every other Swede lives by the coast.[12] Other constraints include lakes and rivers, which are more of a constraint for the inland municipalities. Meanwhile, rugged terrain in steep-slope areas is more prevalent in the north. Steep-slope terrain, and in particular once it has at least

[8] The interested reader is referred to Lind (2002), Lind (2003) and Lind (2012).
[9] Note that the land owner could be a construction company or the municipality itself.
[10] This is comparable to the disincentive of the early exercise of an American call option.
[11] See Fischel (2001).
[12] Statistics Sweden (2012), "Varannan svensk bor nära havet".

a 15 percent slope, can effectively deter construction. As argued in Saiz (2010), such areas are typically regarded severely constrained for residential construction by architectural development guidelines. This variation in topography provides some initial motivation for investigating its potential role as a supply side constraint.

In conclusion, this background provides motivation for studying the role of geography in explaining housing supply elasticities. Substantial regional price variation points at the potential importance of local supply constraints with geography being one such possible constraint. It also justifies the use of a cross-sectional empirical model, such as the one used by Saiz (2010). Moreover, this section highlights certain features of the Swedish housing market; the municipal planning process and a lack of competition in the construction sector, which also appear to act as powerful constraints on supply responsiveness.

3 PREVIOUS RESEARCH

The purpose of this section is threefold. Section 3.1 introduces the conceptual framework used in the literature to investigate the relationship between regional house price variation and housing supply elasticities. The next section introduces geography. Within this section, 3.2.1 reviews literature on the role of geography in housing markets. In 3.2.2, a closer description of Saiz (2010) is provided, given its central role in this study. Next, section 3.3 provides an insight into the methodology of estimating housing supply elasticities, with a focus on the use of instrumental variables. It provides a useful background to the empirical design discussed in section five. Finally section 3.4 summarizes a selection of empirical estimates of elasticities with a focus on the European and Swedish market, to which the results of the current study can be benchmarked against.

3.1 Regional Price Variation and Housing Supply Elasticities

One strand of literature aims at investigating the role of housing supply elasticities in explaining regional price variation (see for instance Green, Malpezzi and Mayo, 2005; Glaeser, Gyourko and Saks, 2006; Glaeser, Gyourko, and Saiz, 2008; Saiz, 2010). For such a link to exist there must be variation across markets in local housing supply elasticities, in turn caused by heterogeneity in local housing supply conditions; something that is often observed in reality (Gyourko, 2009). Conceptually, the mechanism by which this occurs can be thought of as follows. While some markets may exhibit price hikes following housing demand shocks, such as increased immigration, other markets may react less strongly if the housing supply can adjust to accommodate for the new demand. In this framework, the responsiveness of the housing supply, or the elasticity, determines the extent to which prices adjust.

Several studies find that local housing supply elasticities play a role in explaining regional price variation. Constructing an index on land use regulation using two surveys, Glaeser, Gyourko and Saks (2006) use the intensity of regulation as a proxy for housing supply elasticities and investigate if this proxy has an impact on the extent to which productivity shocks are capitalized into house prices[13] across 118 metropolitan statistical areas (henceforth MSAs) for the periods 1980-1990 and 1990-2000. The authors find that an increase in productivity has a 40 percent smaller effect on house prices in less regulated MSAs.

As an alternative proxy for supply elasticities and to avoid the endogeneity[14] associated with regulatory constraints, Glaeser, Gyourko and Saiz (2008) instead use a measure of undevelopable land constructed by Saiz (2008). Estimating a simultaneous equation model of house prices and permits, separately for boom and bust periods for 79

[13] Other variables of interest in the paper include population and income per capita.
[14] Differently put the possibility that regulation not only affects house prices but is also itself affected by house prices.

MSAs in the US, the authors find that the price run-ups of the 1980s were almost exclusively experienced in cities where housing supply was more inelastic. In fact, the most elastic markets (top 33 percent of markets with the highest share of undevelopable land) had an average real price growth of 3.4 percent compared to a 28.6 percent increase in the most inelastic markets during the 1980s boom. Further, the supply elasticity had an effect not only on price growth but also on the duration of a bubble. For elastic places, the average duration of the boom was 1.7 years while it was more than four years for inelastic places.

More recently, Ihlandfeldt and Mayock (2014) estimate short-run elasticities for 63 Florida counties and find that price appreciation is less pronounced and new construction is higher for low elasticity areas.

The selection of studies presented above suggest that heterogeneous local housing supply elasticities play an important role in explaining variation in price changes over time. Clearly, in this framework an important question is what determines these elasticities. While research during the 2000s to a large extent centered on the role of regulation as a determinant, geography has recently gained more attention as a supply-side constraint. Research pertaining to this question is the topic of the next section.

3.2 Geography and the Housing Market

The economic intuition of the role of geography is fairly straight-forward; geographic constraints limit the amount of developable land in an urban area, land which can be considered finite. Given that land is an input in housing production, geographic constraints can limit the supply of housing. By extension, geography could also have an effect on the elasticity of housing supply; a subject which was largely unexplored before Saiz (2010). As a general note, several papers that integrate geography into the study of housing markets spring from the early theoretical models developed by Alonso, Mills and Muth (Bruckner, 1989). One assumption frequently used is that of a monocentric city, i.e. a city with a single employment center (DiPasquale and Wheaton, 1996).

Geography as a Supply Side Constraint

The role of geography is perhaps best understood by making a distinction between physical space and urban land (Rose, 1989a). Although cities or urban areas for practical purposes may be viewed as having an infinite supply of land surrounding the center—an assumption which is particularly intuitive when there are no neighboring urban areas in proximity—the supply of *urban* land can be viewed as finite. Parcels of land located far away from the center of the urban area are intuitively of much less value than those located close to the center. Similarly, geographic constraints such as the existence of water bodies can effectively act as greater constraints if they are located close to the center. From this perspective, by assigning parcels of land far away from the center of the urban area less weight, one can calculate urban land supply as the sum of the weighted land parcels. By construction this sum will be finite.

In the theoretical model used by Rose (1989a), which is based on a monocentric model, the weight that is assigned to a parcel of land is a function of distance. Increasing the distance, weights converge to zero. Other factors that are taken into account in the model include transportation costs and the number of centers if the urban area is not monocentric.[15] Within this framework, Rose (1989a) calculates the extent to which large bodies of water restrict urban land supply, constructing land supply indices for 40 urban areas in the US in 1980. The index shows that Atlanta, for instance, is hardly geographically constrained at all, while Miami and Chicago are relatively more constrained.

In an extension, Rose (1989b) analyzes the importance of natural and man-made constraints on the land price differential of 45 urban areas in the US and finds that both constraints account for 40 percent of the typical differential. The method used resembles the theoretical approach of Rose (1989a); land parcels of the urban area are assigned weights that are a function of the distance to the center and rent gradients.[16] To investigate the role of geographic constraints in explaining cross-MSA house price variation, Chun, Green and Malpezzi (1998) measure natural constraints by constructing dummy variables that indicate if the MSA is adjacent to a coastline which is defined as oceans or large lakes, parks, military bases or reservations. The authors conclude that geography matters; the dummy variable for being adjacent to a large park, military base or reservation is positive and statistically significant in various specifications.

In contrast to earlier research, the recent uses of GIS technology allow for a potentially more thorough analysis of the role of geography in urban economics. Burchfield, Overman, Puga and Turner (2006) are able to distinguish between different features of geography by using GIS. The authors find that geographic features such as ground water availability and rugged terrain among other factors increase sprawl, where sprawl is defined as the amount of undeveloped land surrounding the average urban dwelling. Other uses of GIS in related areas include Combes, Duranton, Gobillon and Roux (2006) and Rosenthal and Strange (2008).

One of the important contributions of Saiz (2010) was the construction of a detailed measure of MSA-level undevelopable land. In contrast to the earlier research that focused solely on coastal constraints (see for instance Rose (1989b)) or dummy variables for the presence of geographic constraints (see for instance Chun, Green and Malpezzi (1998)), Saiz (2010) developed a continuous measure of geographic constraints using GIS, capturing the extent to which urban areas were constrained. With this measure, Saiz (2010) was able to evaluate geographic constraints as a potential determinant of housing supply elasticities. Given that this study is a replication of Saiz (2010), a closer description is provided in the following.

[15] This would include urban areas with multiple centers.
[16] Rent gradients are defined as the percentage rate of decline in rent per square foot per mile.

"The Geographic Determinants of Housing Supply"—Saiz (2010)

Processing satellite-generated data on terrain elevation and the presence of water bodies, Saiz constructs a precise estimate of the amount of undevelopable land in MSAs. This measure of undevelopable land is then used to explore the extent to which it has an impact on the housing supply elasticity of MSAs. The conceptual framework underlying the paper stems from the literature on regional price variation and housing supply described in section 3.1 and in particular the research of Glaeser, Gyourko and Saks (2006) and Glaeser, Gyourko and Saiz (2008). Regulation is also incorporated into this framework. I abstract from discussing this, as it is not the focus of this thesis.

The first part of the paper entails a geographic analysis of land availability. A circle with a 50 km radius is drawn around the centroid of a sample of around 100 MSAs with a population above 500,000. The area that corresponds to terrain with an incline greater than 15 percent, wetlands, lakes, rivers, or other internal water bodies within the circle, is defined as the fraction of undevelopable land. Saiz finds that the constructed measure is strongly related to house price growth. Moreover, MSAs that are informally regarded as having an inelastic housing supply are often geographically constrained; they tend to have a large fraction of undevelopable land. Furthermore, an analysis of the partial correlates of the measure of undevelopable land and typical urban growth determinants such as income growth and population growth provide support for the view that this measure is exogenous to local productivity factors.

The second part of the paper develops a theoretical model based on the model of Alonso-Muth-Mills that shows how land unavailability can impact the housing supply elasticity, and not only the housing supply. Here I refrain from re-deriving the model of Saiz (2010), but instead provide a background of the theoretical setting relevant to the empirical estimation. The setting is that of a circular[17] city k with radius Φ_k. In Table 1 and Table 2, the key ingredients of the theoretical setting are provided.

TABLE 1
Selection of Parameters from the Model of Saiz (2010)

Parameters	Interpretation
Φ_k	Radius of city k
H_k	Housing stock of city k
γ	Units of land/housing space consumption (constant parameter)
Λ_k	Share of available land in the circular city (a sector)
CC	Construction costs
LC	Land costs
$\widetilde{A_k}$	Amenity level of city k
$\widetilde{w_k}$	Wages in city k
$\psi + \alpha$	Marginal congestion costs
i	Discount rate
t	Transportation costs

Source: Adapted from Saiz (2010)

[17] Note that this is essentially the mirror image of the assumption of monocentric cities.

TABLE 2
Overview of the Theoretical Setting of Saiz (2010)

Relation	Equation	Interpretation
Land availability and the city radius	$\Phi_k = \sqrt{\frac{\gamma H_k}{\Lambda_k \pi}}$	The greater the housing stock, the greater the radius of the city.
Profitability condition	$P(d) = CC + LC(d)$	Construction will only occur if the house price covers the total cost. This is the profitability condition of developers (d).
Demand schedule	$\sqrt{H_k} = \frac{\widetilde{A_k} + \widetilde{w_k}}{\psi + \alpha} - \frac{i}{\psi + \alpha} P(0)$	Quantity of housing demanded in city k increases with the amenity level and wage level of the city and decreases with the discount rate. Naturally, quantity demanded is negatively related to prices.
Supply schedule	$\widetilde{P}_k^S = CC + \frac{1}{3i} t \cdot \sqrt{\frac{\gamma H_k}{\Lambda_k \pi}}$	Housing supply is positively related to house prices and negatively related to construction costs.

Source: Adapted from Saiz (2010)

The key equation of the table is the profitability condition and the supply schedule. The important message is that land availability enters the supply of housing decision. Another feature worth emphasizing is that the demand schedule is determined by two forces; amenities and labor wages that (naturally) do not enter the supply schedule. From an econometric point of view, the theoretical setting suggests that amenities and labor wages satisfy the exclusion restriction for instrumental variables estimation. By using alternate demand shocks that are amenity and wage driven, the supply schedule can be traced out. Section 3.3 provides a discussion of this.

Based on the theoretical model, Saiz (2010) derives three implications. Here the derivation of the first proposition is provided, as it is the main focus of this study. For the derivation of the other two, see Appendix I of Saiz (2010).

TABLE 3
Theoretical Propositions from Saiz (2010)

Propositions	Description
Proposition I	The inverse elasticity of supply is decreasing in land availability.
Proposition II	Metropolitan areas with low land availability tend to be more productive or to have higher amenities.
Proposition III	Population levels in the existing distribution of metropolitan areas should be independent of the degree of land availability.

Source: Adapted from Saiz (2010)

To infer the relationship between the elasticity of supply and land availability, first, the elasticy of housing supply is intuitively defined as the percentage change in housing supply as a result of a percentage change in prices. In the mathematical setting, the inverse housing supply elasticity can thus be defined as the derivative of the price of housing in city k, with respect to the housing supply in city k: $\beta_k^S = \partial \ln \widetilde{P_k} / \partial \ln \mathrm{H}_k$. Using the supply schedule expressed in Table 2, the derivative corresponds to expresion (i) below. The relation between the housing supply elasticity and land availabilty is found by taking the derivative of the newly derived housing supply elasticity with respect to land availability. Since this expression is negative, the inverse housing supply elasticity is decreasing in land availability. This implies the housing supply elasticity is increasing in land availability.

$$\beta_k^S = \frac{\partial \ln \widetilde{P_k}}{\partial \ln \mathrm{H}_k} = \frac{1}{2}\left[\frac{\frac{1}{3i} t \sqrt{\frac{\gamma H_k}{\Lambda_k \pi}}}{\widetilde{P_k}}\right] \qquad \text{(i)}$$

$$\frac{\partial \beta_k}{\partial \Lambda_k} = \frac{\partial^2 \ln \widetilde{P_k}}{\partial \ln \mathrm{H}_k \partial \Lambda_k} = -\frac{1}{4}\left[\frac{\frac{1}{3i} t \sqrt{\frac{\gamma H_k}{\Lambda_k{}^3 \pi}}\, CC}{\widetilde{P_k}^2}\right] < 0 \qquad \text{(ii)}$$

Establishing whether proposition I holds in the Swedish context, is the purpose of this thesis. The transition from the theoretical model above to the empirical counterpart is postponed to section 5.1. A background to the empirical design of Saiz (2010) is provided in section 3.3 and a further discussion is provided in section 5.2.

Saiz (2010) found that geography plays an important role in explaining the elasticity of housing supply for the sample of approximately 100 MSAs studied. The population-weighted average elasticity of supply was found to be 1.75, while the unweighted average was 2.5.

Since the publication of Saiz (2010), a number of studies have made further investigations into the role of geography. For instance, Huang and Tang (2012) find that land use regulations and geographic constraints are associated with booms and busts in housing prices. Paciorek (2013) finds that "regulation and geographic constraints play critical and complementary roles in decreasing responsiveness of investment to demand shocks". Paciorek (2013) also extends the analysis to explore the effect not only on house price growth but also on volatility. The author finds that inelasticity is associated with increased price volatility.

Having estimated and analyzed housing supply elasticities, Ihlandfeldt and Mayock (2014) proceed by investigating the relationship between the estimated elasticities and constraints including the amount of undevelopable land, as defined by the authors. The authors find that undevelopable land has a statistically significant effect on supply elasticities.

In contrast, using a panel dataset of 353 local planning authorities in England from 1974 to 2008, Hilber and Vermeulen (2015) find that the "effect of constraints due to scarcity of developable land is largely confined to highly urbanized areas" and "uneven topography has a quantitatively less meaningful impact". Regulatory constraints on the other hand were found to be of importance in explaining the house price-*earnings* elasticity.

3.3 Estimation of Housing Supply Elasticities

A vast amount of literature is devoted to estimating and analyzing housing supply elasticities and price responsiveness. Consistent estimation in this context is a non-trivial matter because of threats to endogeneity, in particular in the cross-sectional literature. As argued by Gyourko (2009) an important area for future work must be the development of robust estimates of local market supply elasticities. Note that the motivation of the estimation of *local* supply elasticities springs from the empirical evidence of regional price dispersion discussed in the previous section.

In retrieving estimates of housing supply elasticities, two main strands of literature exist. In the time-series literature, the dynamics of the housing market with its inherent lags in construction have made vector error correction models (VECMs) a popular choice for estimating short and long-run dynamics.[18] Some studies use the cointegrating vector in such a model of housing supply and house prices as an estimate of the long-run elasticity of supply, also referred to as the price-responsiveness of housing supply (see for instance Wheaton, Chervachidze, and Nechayev (2014)).

The other strand of literature instead exploits regional variation in house prices, within or between countries, in a cross-sectional setting. The framework presented in section 3.1 for instance, is suitable for analysis using cross-sectional data. It is also the approach of this study. In reality, the split between the two methodologies is not necessarily as clear as it is presented here. For instance, a number of papers combine both methods; in a first step the elasticities are estimated using an error correction model and in the second step the estimated elasticities are regressed on a set of hypothesized supply side constraints in a cross-sectional setting (Ihlandfeldt and Mayock, 2014; Oikarinen, Peltola, and Valtonen, 2014) to evaluate the extent to which the supply side constraints can explain the estimated elasticities.

To estimate the elasticity of the housing supply curve, a first step requires the estimation of the supply curve itself. If housing markets clear, the observed equilibrium price and quantity is the result of both demand and supply forces. In econometric jargon, prices and quantities are determined by a simultaneous equations model consisting of the (structural) supply and demand equation. Therefore, the supply equation cannot be estimated as a stand-alone equation and a simple OLS estimation will result in a reverse causality bias.

For identification of the supply equation, the rank condition is a necessary condition. It requires that the demand equation contains at least one exogenous variable (with a coefficient different from zero), that can be excluded from the supply equation (Wooldridge, 2008). This can be viewed as an exclusion restriction. Conditional on identification, the structural (supply) equation can be estimated consistently using 2SLS. The exogenous variable of the demand equation identified by the rank condition is used as an instrument for housing supply and is commonly referred to as a demand-

[18] See for instance Caldera-Sanchez and Johansson (2013) and Wilhelmsson (2008) for a European and Swedish application.

shifter. Intuitively, by exploiting variation in these demand shifters, the supply curve can be traced out. Then the estimated slope of the supply curve yields the elasticity.

What constitutes a suitable demand shifter and in other words a valid instrument therefore becomes an important question in this context. Instruments are valid if they satisfy the exclusion restriction and have a strong first stage. Certain measures of local demand shocks have proven to be particularly useful instruments for housing supply. A host of papers[19] including Saiz (2010) have used the Bartik instrument (Bartik, 1991) to capture shifts in local labor demand that come from national shocks (Baum-Snow and Ferreira, 2015). The Bartik instrument predicts the employment growth that would have occurred in the region if the only source of growth were that of national growth. Differently put, it purges out local variation in employment. The exogeneity of the instrument relies on the assumption that the growth of each local market is as good as exogenous to national growth. To avoid this assumption, a slightly different approach seen in the literature is to compute artificial national growth rates that capture the growth rate of all local markets *except* for the market which the Bartik instrument is constructed for.

Other instrument candidates used are climate related. Saiz (2010) uses the average January hours of sun as a demand shifter. The argument provided in Saiz (2010) for using the average January hours of sun is that it captures a "trend of increasing demand for high-amenity areas". As Rappaport (2007) writes, an analysis of movement patterns suggests that nice weather is increasingly regarded as a consumption amenity. Most strikingly, "weather – measured by January temperature or precipitation – is the single most important determinant of population or housing price growth at the county level in the United States" (Glaeser, Kolko and Saiz, 2001). All this suggests a strong first stage between house prices and weather variables.

To identify the causal effect of unaffordable housing on employment growth in California municipalities, Chakrabarti and Zhang (2014) use the average July maximum temperature and the average January minimum temperature interacted with electricity price variables to instrument for housing affordability. The authors point at the risk of the exclusion restriction not holding due the same reasons presented by Rappaport (2007), i.e. cities with nice weather may attract residents. On the other hand it is argued that there is no strong reason to believe that these amenities would affect employment growth directly. In either case, this would not matter if one assumes equilibrium at start, i.e. weather-induced migration has reached equilibrium before the study period.

As a final note, although exogeneity is impossible to prove, testing for over-identifying restrictions when multiple instruments are available can aid in selection. However, a test for over-identifying restrictions is most meaningful when the instruments are of different nature. From this perspective suitable candidates include historical and geological variables (Combes and Gobillon, 2014).

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[19] See for instance Blanchard and Katz (1992), Glaeser, Gyourko and Saks (2008), Saks (2008), Notowidigdo (2011), Paciorek (2013). See Agell and Öster (2007) for an application in the Swedish context (although not related to housing markets).

3.4 Estimates of Housing Supply Elasticities

Consensus on estimates of housing supply elasticities are generally lacking (Harter, 2004) and estimates appear to be sensitive to the various specifications used. While earlier research reported national elasticity estimates, recent research is increasingly concerned with the estimation of regional elasticities. The literature is predominantly focused on the American market, which in various respects differs from many of the less densely populated urban areas of the European countries.

In the US, DiPasquale and Wheaton (1994) find an elasticity estimate in the range of 1.0-1.4 for the period 1963-1990. For a slightly different time frame, namely 1950-1994, Blackley (1996) finds an elasticity in the range of 1.6-3.7. A regional estimation is performed by Green, Malpezzi, and Mayo (2005) for the period 1979-1996. The results indicate substantial regional variation with Pittsburg displaying the lowest (statistically significant) elasticity of 1.43, while Atlanta with an elasticity of 21.6 has the highest. More recently, Wheaton, Chervachidze, and Nechayev (2014) find elasticities across MSAs in the range 0.2-8.1 for the period 1980-2014.

In Europe, the paper by Oikarinen, Peltola, and Valtonen (2014) is interesting for purposes of comparison. The authors explore regional variation in housing supply elasticities across a selection of cities in Finland and investigate potential elasticity determinants. The authors stress their contribution in terms of conducting the elasticity analysis on a market vastly different from the American, namely "a small sparsely populated country". Error correction models are used to estimate the city-level elasticities. This analysis is then complemented with a cross-sectional regression of the estimated elasticities on potential determinants, including a variable measuring the amount of land lost to water bodies. The construction of the geographic variable follows the approach of Saiz (2010); a 5 km radius is used for all cities, and the share of water, but not steep-slope zones, is identified for each circle. The authors find that geographic constraints do explain supply elasticities.

Another study that is interesting for purposes of comparison is by Vermuelen and Rouwendal (2007) who study housing supply responses in the Netherlands; a country with strict land use regulation and a country in which house prices have nearly tripled since the 1970s. The authors conclude that the housing supply is fully inelastic in the short to medium run.

Although section two indicated a low responsiveness of supply in Sweden, and two supply side constraints were presented as possible explanations to the lack of expansion seen during the late 1990s, quantitative studies of the determinants of housing supply elasticities in the Swedish context is lacking. Englund (2011) argues that since house prices have increased much faster than construction costs, the lack of new construction appears to reflect a very low housing supply elasticity. In contrast, Sørensen (2013) argues that the Swedish elasticity is not low in comparison to other countries, when one takes into account the relatively low Tobin's Q ratio in Sweden. Other studies that are not directly related to the housing supply elasticity but more generally to determinants of price change over time include Hort (1998) and Hüfner and Lundsgaard (2007). Hort

(1998) for instance, finds that movements in construction costs, income, and user costs have a significant impact on real house prices for the period 1968-1994. For an investigation of regional price growth, see for instance Berg (2002).

Wilhelmsson (2008) uses an error correction model to estimate the speed of adjustment of house prices at the regional level. The author finds that the speed of adjustment ranges from 16-78%, indicating substantial regional variation in adjustment. Furthermore, the speed of adjustment is inversely correlated with density. Wilhelmsson suggests that this may be explained by the fact that less dense areas also have a larger supply of unexplored land.

In an analysis based on error correction models of a cross-section of countries including Sweden, Caldera-Sanchez and Johansson (2013) find a short-run price responsiveness of supply of -0.126 and a long-run responsiveness of 1.381 for Sweden, for the period 1980 to the mid-2000s.

The objective of Ho (2015) in an IMF policy paper on supply constraints in Sweden resembles the objectives of this paper. In a first step, Ho estimates housing supply elasticities in a vector error correction model at the municipal level for the period 1980-2014. For the sample of municipalities with statistically significant results, the median elasticity found is 0.10. In a second step the effect of supply constraints on price growth is estimated using Generalized Method of Moments (GMM), focusing on the role played by the previously estimated elasticities, as well as a proxy for developable land and population density. All three constraint measures are found to have an impact on price changes.

4 GEOGRAPHY AND LAND IN SWEDEN: A NEW DATASET

This section is structured as follows. First I discuss the delineation of housing markets and the sample selection. This is followed by a description of the process of constructing a measure of undevelopable land. Finally, the exogeneity of the constructed measure is explored.

4.1 The Delineation of Housing Markets

The definition of a housing market is not a trivial one. Although administrative delineations set out the geographic boundaries of a city, the economic activity of cities can be highly interconnected due to the design of transportation networks. This is especially the case if some cities are net labor outflow cities, meaning that a large fraction of its inhabitants regularly commute to other cities for work. This can also have implications for the housing market—with a demand for housing arising in cities close to net inflow cities in which employment opportunities are large. A clear example of this in Sweden is Stockholm and the surrounding municipalities. Ideally, one would therefore want to base any analysis of demand and supply on a market definition which minimizes demand and supply spillovers and internalizes these to the largest extent possible. Local labor markets would be a viable candidate. Unfortunately, the availability of data for local labor markets is limited in the context of housing variables.

Saiz's analysis is based on metropolitan statistical areas. In the US context, these entities are defined by the United States Census Bureau as areas with a core urban area of 50,000 or more population. Each MSA consists of one or more counties and includes the counties containing the core urban area, as well as any adjacent counties that have a high degree of social and economic integration (as measured by time commuting to work) with the urban core.[20] Notice that the unit of analysis in Saiz (2010) is to a higher extent a reflection of local labor markets than administrative boundaries. Equivalents to MSAs in the Swedish context are the cities of Stockholm, Göteborg and Malmö. Since this cannot constitute the sample for a cross-sectional analysis, it not possible to establish MSAs as the unit of analysis either. Most pressingly, a reliable measure of house prices is only available at the municipal level and this governs the choice of housing market. Having established municipalities as the only viable housing market definition due to data availability in the Swedish context, what remains is a critical evaluation of their suitability and a discussion of the possible need to limit attention to a subset of the existing municipalities which in 1993 amounted to 286. As will be seen, this is closely related to the choice of radius.

The MSAs of Saiz's end subsample differ on a range of attributes but are similar in terms of having a relatively large population and a fairly unambiguous core. Similarity along this dimension, in other words being urban, can facilitate the choice of the

[20] United States Census Bureau (2015), "Metropolitan and Micropolitan Statistical Areas Main".

invariant radius. Nevertheless, one critique to Saiz (2010) is the choice of the 50 km invariant radius. For instance, Cox (2011) argues that the measure of undevelopable land is misleading in particular for small MSAs with slopes and water bodies located at a distance so far away from the center that they effectively do not act as binding constraints to residential development. At the same time, the choice of using an invariant radius is critical to the construction of an exogenous measure of land unavailability. Any adaptation of the radius to the characteristics of the particular MSA would make it endogenous. The issue of constructing a land measure that does not truly capture the magnitude of geographic constraints is diminishing in the variation of market size. For instance, according to Cox (2011) the principal urban area of New York is 45 times larger than that of Stockton. Hence, to avoid misleading measures of undevelopable land, it is preferable if the sample of municipalities do not vary excessively in size.

This directs attention to the location from which the radius should emanate, i.e. the centroid, and how to identify it. In Saiz (2010) the choice of working with MSAs ensured the existence of an urban center (see previous definition). The existence of a centroid is the underpinning of the assumption of monocentric cities. If the definition of the market does not enclose a city centroid, a measure of undevelopable land using the radius is not accurate. As it is, the appearances of cities in reality closely resemble that of a monocentric city, in particular if they are urban. Informally, all Swedish municipalities have an unofficial central city ("centralrort"). In fact, in the Housing Market Survey conducted by Sweden's National Board of Housing, Building and Planning one of the survey questions asks the municipality to report whether or not there is a shortage of housing supply in the central city.

Given that some municipalities are not densely populated with a possible scatter of smaller cities, there is an argument for restricting the sample of 286 municipalities to a subsample consisting of those that are considered urban, the underlying assumption being that urban municipalities are more likely to render the monocentric city assumption suitable. The identification of a city center would therefore not merely be a notional one, but also a reliable one. Differently put, one would ensure that the construction of a circle around the informally defined central city encompasses a large portion of the housing market. If so, and according to the theoretical model, geographic constraints within the area are likely to put pressure on prices, so that the general price level observed by the econometrician is to a high extent a reflection of constraints in that area and not elsewhere. More importantly, it ensures that large portions of the housing supply do not stem from a number of small villages located at the outskirts of the municipality, not encompassed by the radius of the city centroid.

Based on these considerations, a first methodological step is to restrict attention to those municipalities that are predominantly urban. To this end, Eurostat's Degree of Urbanization (DEGURBA) classification system is used. The benefit of this classification system is that it is harmonized across member countries of the EU, which facilitates potential future comparisons of research. DEGURBA classifies Local Administrative Units level 2 (LAU2), which in Sweden correspond to the municipalities, into three types of areas: cities (densely populated areas), towns and suburbs (intermediate density areas) and rural areas (thinly populated areas). Cities have at least 50 percent of the population living in urban centers, while towns and suburbs have less than 50 percent of the population living in urban centers but at least 50 percent of the population living in urban clusters. Rural areas have at least 50 percent of the population living in rural grid cells.[21] Municipalities classified as densely populated areas are arguably the preferred choice, but given a limited sample size (only 24 out of 290 are classified as densely populated areas), the sample is extended to also include intermediate density areas. In the classification system of 2011[22] there were in total 111 municipalities classified as either densely populated areas or intermediate density areas. Two out of these 111 municipalities[23] were created after 1993 and are therefore excluded from the sample. Hence, the final sample consists of 109 municipalities that are classified as highly or moderately urban according to DEGURBA. A consideration worthy of mention is the potential problem of applying a classification system that was constructed based on the state of cities in 2011, on cities for a different time period (1993-2003). However, this is likely a minor issue. It may be the case that cities were not as urbanized in 1993 as in 2011, but it is less likely that the distribution of urban cities has changed over time. Even if this were the case, the impact is on the validity of the monocentric assumption rather than anything else. Moreover, Saiz uses the MSA classification of the year of 2000, although his sample dates back to 1970.

The second step is the identification of the centroid. Due to the lack of a formal definition of the center of a municipality I resort to using the informal notion of the central city (as listed on municipality websites). Finally, the choice of an invariant radius is a much more difficult one. Although, the sample is now restricted, some municipalities will still differ largely in their size. Therefore, several different specifications will be adopted to test the sensitivity of the undevelopable land measure to the choice of radius. Oikarinen, Peltola, and Valtonen (2014) use a 5 km radius for the construction of their undevelopable land measure. This is considerably smaller than Saiz's 50 km radius, but the authors argue that it reflects the much smaller size of Finish cities. A similar argument can be applied in the Swedish case. As a benchmark I therefore use a 5 km radius. However, I also perform the same calculations for a 7 km, 11 km and 13 km radius to test the sensitivity of the measure to the choice of radius.

4.2 Constructing a Measure of Undevelopable Land

The geographic analysis needed to construct a measure of undevelopable land is based on geocoded data in the form of shape-files from The Swedish Mapping, Cadastral and Land Registration Authority.[24] My approach closely follows the methodology of Saiz (2010). The data was processed and analyzed in ArcGIS. The unit of analysis is a subset of 109 municipalities regarded as densely populated areas or intermediate density areas

[21] Eurostat (2016).
[22] The classification system is currently being updated.
[23] Nykvarn and Knivsta.
[24] In Swedish: Lantmäteriet.

according to Eurostat's DEGURBA classification. For each such municipality an invariant radius, r, emanating from the central city of the corresponding municipality creates a circle with area πr^2 square kilometers. Based on the critique by Cox (2011) discussed earlier, several alternative invariant radiuses are used to assess the sensitivity of the overall measure to the choice of radius. As a benchmark a 5 km radius is used. A simple visual inspection reveals that the corresponding circle encompasses the entirety of almost all central cities for each of the 109 municipalities.

I use Saiz's definition of undevelopable land and identify three main constraints to the construction of housing. First, steep-slope terrain is identified as zones with an elevation above 15 percent. As argued in Saiz (2010) architectural development guidelines typically deem areas with slopes above 15 percent as severely constrained for residential construction. Next, I calculate the area corresponding to lakes, rivers, wetlands, and other internal water bodies. Finally, I calculate the area lost to oceans and the great lakes. In the following I outline the procedure in ArcGIS used to construct the measure of undevelopable land. For a visual description of the procedure, the reader is referred to Appendix I.

To identify steep-slope zones, The Swedish Mapping, Cadastral and Land Registration Authority's digital elevation model (DEM) at a 50 m resolution is used and areas with slopes above 15 percent within 50 m grids were identified. This is a finer resolution than the one used in Saiz (90 m). The authority is currently working on producing a DEM at a 2 m resolution, but this was not available at the time of writing. In a second step, the GSD General Map was used to identify the presence of water bodies (including wetlands) and oceans. This measure includes at its finest level rivers and internal water bodies that have a width of at least 6 m. For each municipality the location of the central city was identified using the GSD Map of Sweden. As a proxy for the center of a city the location of the main train station is used.[25] For a sample of 70 central cities, a central train station could be identified. For the remaining 39 cities, I use the geographic centroid of the city. A circle with a r km radius is then drawn with either the central train station or the centroid of the city as its center point. The overlap between the area of the circle and the area corresponding to steep-slope zones and internal water bodies including wetlands constitutes the area defined as undevelopable land. The final measure is the ratio of undevelopable land to the area of the circle. A summary of the geodata used is presented in Table 4.

TABLE 4
Sources of Geodata

Measure	Source: The Swedish Mapping, Cadastral and Land Registration Authority
Zones with >15% slope	GSD Elevation Data, grid +50 hdb (raster)
Lakes, rivers, other internal water bodies (incl. wetlands)	GSD General Map (vector)
Ocean	GSD General Map (vector)
Main train station	GSD General Map, (vector)
Administrative boundaries	GSD Map of Sweden 1:1 million (vector)

[25] This is based on the assumption that the railway station is located in the very center of the city. Although not formally tested for, this assumption is likely to hold well in the Swedish context.

The final measure of undevelopable land for the 109 municipalities when using a 5 km radius is presented in Table 5. To the best of my knowledge, this is the first comprehensive measure of undevelopable land in Sweden. From the table it can be seen that there is a large degree of cross-sectional variation, with some municipalities having fractions close to zero, while others are severely constrained. This motivates an investigation of their role in explaining the extensive cross-sectional variation in house prices across municipalities observed in section two.

TABLE 5: Geographic Constraints (5 km Radius), DEGURBA Municipalities

Rank	Municipality	Undevelopable area (%)	Rank	Municipality	Undevelopable area (%)	Rank	Municipality	Undevelopable area (%)
1	Haninge	92.64	38	Halmstad	25.03	75	Finspång	12.21
2	Öckerö	70.85	39	Uddevalla	24.92	76	Kristinehamn	11.42
3	Kalmar	63.64	40	Lerum	23.86	77	Sundbyberg	10.03
4	Oxelösund	52.25	41	Partille	22.74	78	Trollhättan	8.99
5	Ystad	48.69	42	Västerås	22.21	79	Burlöv	8.79
6	Hammarö	46.76	43	Ängelholm	22.18	80	Nässjö	8.46
7	Tyresö	43.73	44	Järfälla	22.18	81	Skövde	8.43
8	Landskrona	43.53	45	Botkyrka	21.60	82	Nyköping	8.04
9	Lidingö	41.83	46	Åmål	20.96	83	Norrköping	8.03
10	Trelleborg	39.81	47	Tranås	20.54	84	Vallentuna	7.80
11	Nacka	37.03	48	Falun	20.50	85	Eksjö	7.43
12	Timrå	36.94	49	Motala	20.46	86	Avesta	7.38
13	Härnösand	36.43	50	Göteborg	20.27	87	Umeå	6.75
14	Lidköping	36.23	51	Södertälje	20.10	88	Borlänge	6.43
15	Mariestad	35.86	52	Mölndal	19.94	89	Örebro	6.01
16	Kiruna	35.55	53	Huddinge	19.67	90	Linköping	5.30
17	Hjo	35.14	54	Karlskoga	18.39	91	Gävle	4.89
18	Västervik	33.88	55	Österåker	18.10	92	Kumla	3.97
19	Jönköping	32.93	56	Täby	17.93	93	Svedala	3.76
20	Ludvika	32.74	57	Boden	16.67	94	Sala	3.19
21	Malmö	32.71	58	Åtvidaberg	16.29	95	Arboga	3.16
22	Östersund	32.17	59	Lycksele	16.24	96	Köping	2.75
23	Sandviken	30.55	60	Solna	16.11	97	Hallstahammar	2.47
24	Helsingborg	30.53	61	Kungälv	16.08	98	Tibro	2.11
25	Luleå	29.55	62	Haparanda	15.90	99	Eskilstuna	1.92
26	Salem	29.46	63	Katrineholm	15.47	100	Sigtuna	1.86
27	Karlstad	29.11	64	Degerfors	15.46	101	Tidaholm	0.96
28	Alingsås	29.10	65	Borås	15.14	102	Åstorp	0.90
29	Vänersborg	27.89	66	Kil	14.80	103	Uppsala	0.83
30	Stockholm	27.65	67	Växjö	14.36	104	Enköping	0.83
31	Danderyd	27.52	68	Surahammar	13.79	105	Nybro	0.26
32	Piteå	26.58	69	Fagersta	13.67	106	Staffanstorp	0.21
33	Sundsvall	26.37	70	Upplands Väsby	13.46	107	Skara	0.10
34	Oskarshamn	25.78	71	Sollentuna	13.30	108	Lund	0.06
35	Gällivare	25.66	72	Hofors	12.62	109	Eslöv	0.02
36	Karlshamn	25.30	73	Håbo	12.55			
37	Habo	25.10	74	Värnamo	12.30			

Although, the role of geographic constraints will be formally tested for in section seven, a back of the envelope comparison of the price appreciation of the most constrained municipalities and the least constrained municipalities (bottom 50 percent versus top 50 percent), may be useful. While the price appreciation is on average higher in the most constrained municipalities, in accordance with the predictions, the difference between the two groups is small (Table 6). The difference is the largest for the municipalities with the lowest price appreciation (bottom ten percent). Within that class the price appreciation for the constrained municipalities was more than twice the appreciation of the least constrained municipalities. Hence, this preliminary data check does not lend strong support to the view that the municipalities associated with the highest price levels are also the most constrained. Further discussion is postponed to section seven in which the importance of geographic constraints is formally tested for.

TABLE 6
Distribution of House Price Growth, 1993-2003

	N = 54 Least constrained (%)	N = 55 Most constrained (%)
Mean	37.6	42.2
Std.dev.	26.8	26.0
10th	7.4	15.6
25th	14.5	24.7
50th	36.5	45.6
75th	59.5	62.4
90th	74.1	74.5

Notes: Sample of 109 municipalities

To assess the sensitivity of the measure of undevelopable land to the choice of radius I perform the steps outlined above for a radius of 7, 11, and 13 km. Simple visual inspection reveals a potential important problem in increasing the radius. As could be seen in the figures of Appendix I, the 5 km radius captured the majority of the area of the central city which also, by the choice of classification system, should hold a large fraction of the housing stock. Increasing the radius, will in some cases lead to the inclusion of land far beyond the borders of the central city. Given the assumption that the central city holds most of the housing stock, the existence of water bodies kilometers away from its border may lead to an overestimation of actual geographic constraints on the housing supply. Similarly, if the 5 km radius does not capture the entirety of the central city, the exclusion of water bodies at the outskirt of the city will underestimate the fraction of undevelopable land. Table 7 compares the distribution of the measure of undevelopable land across the different choices of radius. Table 8 displays the correlation between the different measures. The measure of undevelopable land appears to be quite robust to the choice of radius.

TABLE 7
Summary Statistics of Undevelopable Land for Different Radius Specifications

	Undevelopable land (%)			
	5km radius	7km radius	11km radius	13 km radius
Mean	20.7	21.4	22.6	23.3
Std.dev.	15.9	15.9	15.5	15.4
10th	1.9	2.1	3.6	4.8
25th	8.0	9.9	12.5	13.7
50th	18.1	18.7	20.9	21.6
75th	29.1	30.0	31.0	30.4
90th	37.0	39.5	41.1	42.0

Notes: Sample of 109 municipalities

TABLE 8
Correlation of Undevelopable Land for Different Radius Specifications

	5 km	7 km	11 km	13 km
5 km	1.000			
7 km	0.982	1.000		
11 km	0.932	0.964	1.000	
13 km	0.902	0.934	0.992	1.000

Additional Robustness Checks

From the previous it is clear that municipalities vary substantially in their geography. This certainly motivates the analysis of the role of geography in the dynamics of the housing market. It is however important to keep in mind that there are several caveats associated with the study of geographic constraints in markets that are defined primarily in terms of administrative boundaries. Although the subsample of 109 municipalities are classified as high to intermediate density regions according to Eurostat, in principle the invariant radius approach described above does not guarantee that the entirety of the housing stock of a municipality is analyzed. This is an important limitation of any measure of geographic constraints. As touched upon earlier, the more urban the municipality and thus the higher the concentration of the housing stock to a unique central location, the greater the probability that the measure of geographic constraints reflects the actual constraints faced by the housing market. By this reasoning, the degree of urbanization provides empirical support or critique to the validity of the assumption of monocentric cities. By extension it also reflects the reliability of the measure of geographic constraints.

To evaluate the extent to which the constructed measure of geographic constraints captures the entirety of the municipality's housing stock, I attempt to analyze the distribution of the housing stock. Using data from Statistics Sweden on the composition of the housing stock in 1990,[26] I identify the second and third largest city of the municipality. This data is associated with one important limitation; double counting of the housing stock occurs for smaller municipalities with a housing market that

[26] Such data is not available after 1990.

transitions into the housing market of a bordering municipality.[27] This occurs for 12 out of the sample of 109 municipalities,[28] all of which are located close to the metropolitan statistical areas Stockholm, Göteborg and Malmö. For these municipalities the central city constitutes the absolute majority of the municipality. I therefore limit the analysis of the distribution to the remaining 97 municipalities.

Table 9 presents summary statistics on the distribution of the housing stock for the 97 municipalities. On average 54.0 percent of the municipality's housing stock is located in the central city. The sum of the housing stock in the top three cities is on average 66.8 percent. This implies that the measure of undevelopable land, which has the central city as its centroid, does not capture the entire housing stock of the municipality. This in turn implies that the undevelopable land measure reflects the conditions primarily at the location and in the vicinity of the central city and not necessarily for the entire municipality. Nevertheless, it is likely that it is the housing market of the central city and the associated geographic constraints that are driving the house prices observed at the municipal level. Intuitively, house prices at the central city of the municipality where the majority of the population and jobs are located ought to drive the municipal level house prices. This is however not testable given the unavailability of house price data at the city level.

TABLE 9
Distribution of Housing Supply, 1990

	Cumulative housing stock (%)		
	Central City	Top 2 cities	Top 3 cities
Mean	54.0	62.3	66.8
Bottom 25%	43.2	52.6	56.8
Top 25%	63.0	70.7	75.5

Notes: The sample only includes the 97 municipalities were double counting of the housing stock did not occur. See text for further explanations.

4.3 Exogeneity of Undevelopable Land

Table 10 displays the slope coefficients of regressions of various different variables on the measure of undevelopable land and regional fixed effects. The results are interesting for a couple of reasons. First, the regression of the change in log house prices on the share of undevelopable land yields a coefficient that is significant at the 10 percent level of significance. This motivates further studying the link between house prices and geography. Second, demand drivers such as immigration shocks, average January temperature[29] and hours of sun, and the share of the adult population with a

[27] More specifically, this occurs when the housing stock of the city is included in more than one municipality.
[28] Järfälla, Haninge, Huddinge, Danderyd, Nacka, Salem, Solna, Sundbyberg, Tyresö, Burlöv, Partille, Mölndal.
[29] The average January temperature is close to being significant, with a p-value of 0.114.

post-secondary education of at least three years but not including post-graduate studies, is uncorrelated with the share of undevelopable land. In fact, not even income growth is related to geographic constraints. This enforces the intuitive notion that geographic constraints, which are predetermined, are exogenous to other local conditions, although it is important to note that the table only acts as an indication of exogeneity rather than establishing such a relationship. Various other demand variables could potentially be related to the geographic constraint measure. However, the explanatory variables included in the table are included precisely because they are important demand drivers. The selection of variables also follows Saiz (2010).

Furthermore, the results point at another finding. The regression of the difference in log population on the share of undevelopable land yields a significant slope coefficient. This is a slightly discomforting finding given that the theoretical model developed by Saiz implies that population growth is unrelated to geographic constraints (proposition III). However, it turns out that the significance is driven by an outlier; the municipality of Haninge has an above 90 percent share of undevelopable land. When excluded, the coefficient of the log difference in population is insignificant, in accordance with proposition III. Unfortunately this also reduces the level of statistical significance of the difference in log average house prices. Important to note, the statistical significance/insignificance of all other variables remain the same. Still the relationship between prices and geography remain interesting for two reasons. First, Table 6 presented previously, remains largely unaffected by the exclusion of the outlier, pointing at a difference in price appreciation between high and low constrained municipalities. Second, in a regression where the continuous share of undevelopable land is replaced by a binary indicator of high and low constrained municipalities, the estimated coefficient is almost significant at the ten percent level of significance.[30]

All in all the discussion from this section provides support to the view that the measure of geographic constraints constructed is exogenous to other (demand side) factors. There is less support to the view that there is a positive relationship between geographic constraints and price appreciation. It is possible that the relationship is non-linear; small increases in the fraction of undevelopable land may not be associated with corresponding increases in price appreciation. It may instead be the case that undevelopable land puts a pressure on prices once it has reached a certain threshold, after which it starts to act as a constraint. In any case, the simple regressions presented here do not give a conclusive picture of the relationship between prices and geographic constraints. This relationship is explored more formally in section seven.

[30] P-value of 0.108.

TABLE 10

Slope Coefficients of Undevelopable Land (5km Radius)

	Share of Undevelopable Land
	OLS-Regional FE
	Β
Log average house price (2003)	0.700***
	(0.244)
ΔLog average house price (1993-2003)	0.218*
	(0.116)
Log income (2003)	0.144**
	(0.0605)
ΔLog income (1993-2003)	0.0152
	(0.549)
Log population in 2003	0.358
	(0.496)
ΔLog population (1993-2003)	0.0770**
	(0.0352)
Immigration shock	0.00572
	(0.0128)
Average January temperature, Celsius	1.191
	(0.747)
Average January sunshine duration, hours	-0.0712
	(0.205)
Share with bachelor's degree	-0.0954
	(0.370)
Observations	109

Notes: Each row coefficient (*Β*) represents a regression of the row variable (dependent variable) on the share of undevelopable land (explanatory variable). Robust standard errors are given in parenthesis. All specifications include regional fixed effects (Norrland, Svealand, Götaland). The log average price change is calculated as a change in the purchase price coefficient; an index-proxy described in detail in section six. *** p<0.01, ** p<0.05, * p<0.1

5 EMPIRICAL DESIGN

The estimation of the housing supply elasticity and the role of geographic constraints rely on an empirical specification that is driven by both theoretical and econometric considerations. In deriving the empirical specification, the theoretical expression for the profitability condition of developers is used, following Saiz (2010). This derivation is presented in section 5.1, together with the two main hypotheses of interest. In the following section, the IV estimator is proposed as a mode of estimation to avoid simultaneity bias. The discussion of possible instruments in this section further builds on the review of the previous literature (section 3.3) and Saiz (2010).

5.1 Theoretical Foundation

To estimate the elasticity of housing supply the empirical counterpart of the theoretical expression for the profitability condition of supply is used. This derivation is shown below and follows Saiz (2010):

$$P_m = CC + LC(H_m)$$

where P_m is the average house price in municipality m. On the supply side, it is equal to the sum of construction costs (CC) and land values (LC). While construction costs do not depend on the housing stock (H_m) land values do. Notice that there is no subscript on construction costs, under the assumption that construction costs are a function of factor prices that are determined at a national or international level. Taking logs and totally differentiating the expression yields

$$d \ln P_m = \frac{dCC}{P_m} + \frac{dLC(H_m)}{dH_m} \cdot \frac{H_m}{P_m} \cdot \frac{dH_m}{H_m}$$

Defining $\sigma_m = CC/P_m$ as the ratio of construction costs to house prices in 1993, and assuming that the change in house prices resulting from a change in the housing stock is equivalent to the corresponding change in land values $dP_m/dH_m = dLC(H_m)/dH_m$, the expression above can be rewritten as follows

$$d \ln P_m = \sigma_m \cdot \frac{dCC}{CC} + \frac{dP_m}{dH_m} \cdot \frac{H_m}{P_m} \cdot \frac{dH_m}{H_m}$$

Since the elasticity of housing supply for any municipality m is given by $(dH_m/H_m)/(dP_m/P_m)$ the expression can be rewritten once again as

$$d \ln P_m = \sigma_m \cdot \frac{dCC}{CC} + \beta_m \cdot \frac{dH_m}{H_m}$$

where β_m is the inverse housing supply elasticity. This is the empirical log-linearized supply equation. Assuming discrete decadal changes (1993-2003), the empirical supply equation can be estimated in a regression framework and the estimate of $1/\beta_m$ can be interpreted as the average housing supply elasticity. To incorporate for the effect of geographic constraints, the implication of Saiz's model is that the municipality-specific parameter β_m is a function of available land Λ_m such that $\beta_m = \beta + (1 - \Lambda_m)\beta^{LAND}$. Substituting for β_m the empirical log-linearized supply equation that incorporates the effect of geographic constraints can be expressed as follows

$$d \ln P_m = \sigma_m \cdot \frac{dCC}{CC} + \beta \cdot \frac{dH_m}{H_m} + (1 - \Lambda_m)\beta^{LAND} \cdot \frac{dH_m}{H_m}$$

In this framework β can be interpreted as the *average* inverse housing supply elasticity for municipalities with no fraction of undevelopable land. For municipalities with a fraction of undevelopable land, there is an incremental effect of house price growth. Following the reasoning in Saiz (2010), if price appreciation is higher in more geographically constrained areas, β^{LAND} is positive. If it is positive, a one percent increase in the housing stock of a municipality with 100 percent undevelopable land, leads to a price appreciation that is β^{LAND} percent higher than that of a municipality with 100 percent developable land. Hence, based on the reasoning in Saiz (2010), one can set up the following hypotheses

Hypothesis 1: The average (inverse) housing supply elasticity is positive or alternatively, the housing stock responds to price changes:

$$H_0: \beta = 0$$
$$H_1: \beta \neq 0$$

Hypothesis 2: The average (inverse) housing supply elasticity is a function of geographic constraints. This is a test of proposition I in Saiz (2010).

$$H_0: \beta^{LAND} = 0$$
$$H_1: \beta^{LAND} \neq 0$$

5.2 Empirical Specification

Replacing the derivatives with discrete (decadal) changes, yields equation (1). This empirical specification exploits cross-sectional variation in house price growth across the 109 municipalities. The left hand side variable is the SEK change in house prices for a municipality *m*, from 1993 to 2003. On the right hand side, σ_m is the municipality-specific parameter as previously defined. Since it is known it can be calibrated into the model.[31] This implies that (1) explicitly takes into account the impact of construction costs on house prices.

$$\Delta \ln P_m = \sigma_m \Delta \ln CC + \beta \Delta \ln H_m + \sum R_m^j + \varepsilon_m \tag{1}$$

[31] In practice this means that (1) will be estimated with $(\Delta \ln P_m - \sigma_m \Delta \ln CC)$ as the left-hand side variable.

The main explanatory variable is the change in the log housing stock for each municipality between 1993 and 2003 and β is the estimate of the inverse housing supply elasticity. To this regional dummies are added to account for regional fixed effects. Municipalities correspond to one of the three regions (j=1,2,3), Norrland (north), Svealand (mid-regions) or Götaland (south). This regional classification is broad enough to allow for sufficient variation within the group while still capturing important variation across regions. However, for robustness, alternative regional fixed effects are used as well. Equation (1) is the baseline regression of this study. Later it will be augmented to investigate the effect of undevelopable land.

The main empirical challenge to (1) is the endogeneity of housing supply. The price observed by the econometrician is a function of both demand and supply forces and therefore OLS will result in simultaneity bias. As discussed in section three, one possible solution is to instrument for the housing stock using demand shifters. Valid demand shifters should satisfy a strong first stage and the exclusion restriction. In others words, the correlation between the chosen instruments and housing supply should be high (strong first stage) and the only channel through which the instruments affect house prices should be through housing supply (exclusion restriction). Saiz instruments for the housing stock using the Bartik instrument, an immigration shock as well as the average hours of sun in January for the time period considered. With an F-statistic above 13.91, the immigration shock, Bartik instrument and the average January *temperature*, satisfy the relevance assumption also in the Swedish context, and are not regarded as weak, something I will elaborate on further in section seven. Here I provide an economic justification for the relevance condition and the exclusion restriction of the instruments.

As argued in Saiz (2010) weather conditions are an important determinant of housing demand. In the US, the average hours of sun in January is the single most important determinant of house price growth (Glaeser, Kolko, and Saiz, 2001). Assuming similar preferences exist in the Swedish context, one would expect a positive relationship between housing supply and average hours of sun in January. In fact, the shape of the country yields large variation in exposure to sunlight between municipalities located in the very north and south parts. With extensive variation, the effect of weather conditions on housing supply may be more accurately estimated. In section seven the relevance of the weather instrument is tested for in the first stage regression. Two different proxies for weather conditions are used: average duration of sunlight in January measured in hours as well as the average (land) temperature in January, measured at the centroid of the municipality. Given that the exclusion restriction is not testable, I assume for now as in Saiz (2010) that it holds. On an intuitive level, it appears reasonable to assume that weather conditions do not have an impact on prices, other than through demand. Certainly, in the theoretical expression of the supply function, this is intuitive.

Similarly, immigration is an important determinant of housing demand. To accommodate migrant inflows the housing supply has to adjust upwards. The strength of the correlation between immigration and housing supply is also tested for in section seven. A priori the relationship is assumed to be positive. Saiz provides support for the validity of the exclusion restriction with reference to research on immigration patterns in the American context, which suggests that inflows are largely unrelated to citywide economic shocks but rather determined by predetermined settlement patterns of immigrant communities. Similar research in the Swedish context is lacking and therefore this assumption should be kept in mind.

The final demand shifter considered is employment growth. To capture shifts in local labor demand that come from national shocks, the Bartik instrument is used. The Bartik instrument for municipality m is given by the sum of the employment share of industry i, in municipality m, in the base year multiplied by the national growth rate of industry i over the period of study. As such the instrument predicts the employment growth that would have occurred in the municipality if the only source of growth were national growth. Given that local growth rates do not enter the computation of the Bartik instrument, the instrument does not capture local productivity shocks and can therefore be argued as exogenous. However, this notion of exogeneity, relies on the assumption that the growth of each local market, and in this case each municipality, is as good as exogenous to national growth. With 286 municipalities in 1993, the impact of the average municipality on the national growth rate is arguably marginal. There is one clear exception; the municipality of Stockholm which holds the capital city. To account for this, and in line with recent research, heterogeneous growth rates are used. As described in section three, this means that the local market's employment share is multiplied by an artificial national growth rate which captures the growth rate of all local markets *except* for the market which the Bartik instrument is constructed for.

Given a strong first stage and the validity of the exclusion restriction, the elasticity of supply is estimated in the following way using two-stage least squares

$$\Delta \ln P_m = \sigma_m \Delta \ln CC + \beta^{IV} \Delta \ln \widehat{H_m} + \sum R_m^j + \varepsilon_m \qquad (2)$$

$$\Delta \ln H_m = \omega + \gamma_1 Bartik_m + \gamma_2 imm_m + \gamma_3 climate_m + \sum R_m^j + \zeta_m \qquad (2a)$$

To capture the effect of geographic constraints, (2) is augmented with the measure of undevelopable land previously constructed.

$$\Delta \ln P_m = \sigma_m \Delta \ln CC + \beta^{IV} \Delta \ln \widehat{H_m} + \beta^{LAND}(1-\Lambda_m)\Delta \ln \widehat{H_m} + \sum R_m^j + \varepsilon_m \qquad (3)$$

Saiz (2010) also considers the possibility that the effect of geography on price appreciation is solely a "coastal effect". From this perspective, what makes markets more inelastic is the fact that they are coastal and other topographic constraints do not matter. To investigate whether the effect of geographic constraints is driven by being a coastal market a fourth specification is

$$\Delta \ln P_m = \sigma_m \Delta \ln CC + \beta^{IV} \Delta \ln \widehat{H_m} + \beta^{LAND}(1-\Lambda_m)\Delta \ln \widehat{H_m} + \beta^{COAST} Coast \Delta \ln \widehat{H_m} + \sum R_m^j + \varepsilon_m \qquad (4)$$

where $Coast$ is a dummy variable taking on the value one if the municipality is a coastal municipality, i.e. if it borders any ocean.

At this stage, a remark on the choice of the time period is warranted. The time period of consideration, 1993-2003, yields an estimate of the housing supply elasticity which is based on decadal changes in the housing supply. It is debatable whether the length of the time period is sufficiently long to allow for an estimation of a long-term housing supply elasticity parameter, given the considerable response slack in housing markets. Glaeser, Gyourko and Saks (2006) argue that a ten year frequency allows for an estimation of the relatively long-run behavior of housing prices. It is however possible that lower time frequencies of 20 or 30 years which yield estimates of elasticities that can truly be considered long-term, are potentially more interesting. For this reason Saiz (2010) bases the estimation on a time period of 30 years. In any case, the choice of the length of the period is arguably a function of the specifics of the housing market and the extent to which the housing market exhibits slack.

Restricted by the need of a consistent industry classification system, a time interval of more than ten years was not possible in this paper. More specifically, the industry classification used in this paper is based on SNI92. This system was enforced in 1992. It was predated by SNI79 and replaced by SNI2002 in 2002, although data for 2003 which is based on the SNI92 system is still available. The current system is that of SNI07, which was introduced in 2007. Although industry classification conversion keys exist, they apply to the five-digit level and such data was not available for this paper. Hence, the most recent classification system that lasted for at least ten years is that of SNI92 and the corresponding period is 1993-2003.

6 DATA AND SUMMARY STATISTICS

The analysis focuses on a subset of the 286 municipalities in 1993 that are regarded as densely populated areas or intermediate density areas according to Eurostat's Degree of urbanization (DEGURBA) classification, for the period 1993-2003. The earliest year for which the DEGURBA classification is available is 2011. 111 out of 290 municipalities were at this point classified as either densely populated areas or intermediate density areas. Two of these municipalities, Nykvarn and Knivsta, were formed in 1999 and 2003 respectively and are therefore excluded from the sample. This reduces the sample to 109 municipalities. Variables relevant to the empirical estimation include housing market variables (house prices, housing stock, construction costs) and demand shifters (immigration shock, Bartik instrument, climate variables). These are described in detail below together with the associated summary statistics.

6.1 Housing Market Variables

House Prices and the Housing Stock

A vast literature concerns the choice of a suitable measure of house prices. Simple price indices based on mean house purchase prices at a specific point in time do not take into account the characteristics of the building sold (Berg, 2002). Ideally, a measure of house price changes should reflect the price change of the "same" house, excluding other factors such as quality. To this end a constant quality index should be used, to reflect changes in prices that are not driven by changes in quality. The Real Estate Price Index for one and two dwelling buildings provided by Statistics Sweden is such a measure but it does not exist at the municipal level. As an alternative, at the municipal level, Statistics Sweden makes use of the purchase price coefficient. The unweighted purchase price coefficient is the ratio of the average purchase price and the average assessed property value which is based on tax assessments conducted by the tax authorities, averaged over the number of properties sold

$$\left(\frac{P}{A}\right)_{m,t} = \frac{1}{N}\sum_{i=1}^{N}\frac{P_{i,m,t}}{A_{i,m,t}}$$

where P is the purchase price of a one or two dwelling building *i* in municipality *m* at time *t*, *A* is the corresponding tax assessment value and *N* is the number of sold one/two dwellings. Viewing the tax assessment value as the market value of the house at a specific point in time, it may be used as an index of housing quality (Berg, 2002). As an example, if the coefficient for a particular house *i*, is 1.50, this indicates that the house was sold at a 50 percent premium above its assessed value.[32] By comparing the purchase

[32] B0 41 SM 0401 (2003), see p.35.

price coefficient between two periods, rather than the average purchase price, changes in quality are taken into account. Because revisions of tax assessments can cause breaks in the data series for the average tax assessed values,[33] such changes have to be taken into account. Using conversion keys provided by Statistics Sweden for the years 1996 and 2003 when tax assessments were conducted, the purchase price coefficient of 2003 is made comparable to that of 1993. The final measure of growth is the log difference between the purchase price coefficient in 2003 and 1993, deflated by the CPI to obtain real house price growth. During the period, the CPI grew by approximately 14 percent.

Data on the housing stock is retrieved from Statistics Sweden. Important to note, Statistics Sweden only provides data on the projected housing stock for the period 1990 and onwards. More specifically, the housing stock for each of the years following 1989 is calculated by adding new construction and removing demolished houses.

Table 11 reveals considerable heterogeneity in the average price increase over the period 1993-2003 across the municipalities. While the average real price increase during the period was approximately 54 percent, the top ten percent of municipalities had more than double the average growth. The bottom ten percent had less than a fifth of the average growth. This variation is also reflected in a high standard deviation. The evolution of the housing supply creates a sharp contrast. On average the housing supply increased by approximately 3 percent, but the standard deviation is very high, reflecting a large dispersion across municipalities. While the top ten percent saw an increase of almost 9 percent, the bottom ten percent saw an increase of less than 1 percent.

TABLE 11
Summary Statistics of House Price and Housing Supply Growth, 1993-2003

	Prices		Supply
	Nominal (%)	Real (%)	(%)
Mean	76.01491	54.15465	3.108
Std.dev.	44.94595	39.36387	3.324
10th	24.08325	8.67267	0.309
25th	42.67679	24.95698	0.633
50th	67.95361	47.09453	1.417
75th	110.3564	84.23107	4.937
90th	140.597	110.7159	8.959

Notes: Percentage changes in house prices are measured by the evolution of the unweighted purchase price coefficient. Sample of 109 municipalities.

Construction Costs

Following Saiz (2010) and Oikarinen, Peltola, and Valtonen (2014), I use a nationwide measure of construction costs. The argument put forward by Saiz is that prices of material and timber are determined at the national or international level and the construction sector is typically competitive. Given the current discussion of the

[33] For the period 1990-2003, tax assessments were conducted in 1990, 1996 and 2003.

competitiveness in the Swedish construction industry,[34] or the lack thereof, there may be reasons for questioning this assumption. By measuring the growth of regional construction costs instead of nationwide costs, the assumption can be relaxed. However, raw construction cost data are not available at the municipal level by Statistics Sweden, but only at a higher regional level. This would result in a very crude measure of regional construction costs.

There is another benefit with using an aggregate measure of construction costs in Sweden rather than regional costs. An important issue with construction cost data pertains to changes in quality of constructed houses. Ideally, one would want to capture changes in construction costs for the same typical house over time, so that potential increases in construction costs do not reflect the fact that companies are constructing houses of better quality. To this end indices are used. However, the typical construction cost indices available by Statistics Sweden do not exist at the municipal level. In the Swedish context, there is reason to believe that the characteristics of the average home changed considerably during the relevant period.[35] This provides further motivation for assuming homogenous construction costs and using a nationwide construction cost index. One should however keep in mind the drawback of using an aggregate index; regional variation in construction costs is not captured and there is reason to believe that such variation exists in the Swedish case. Later I will relax the assumption of homogenous costs and assess the sensitivity of the results to the assumption.

To capture the growth of construction costs, $\Delta \ln CC$, over the period 1993-2003 I use the growth of the factor price index[36] deflated by the producer price index. Over this period, the factor price index grew by approximately 33 percent in nominal terms, and 14 percent in real terms. The proxy for the municipal level intercept, σ_m, is constructed as follows. The denominator is the nationwide net building cost per total primary utility floor space in square meters for newly constructed conventional collectively built one or two dwelling buildings in 1994.[37] The costs are calculated with deduction for subsidies. The total primary utility floor space is defined as the sum of useful floor space and other common area of the dwelling. Here it will serve as a measure of the size of the average one or two dwelling building. To calculate the construction cost associated with the average one or two dwelling building, the net cost is multiplied by the average total primary utility floor space. The resulting measure of the construction cost of a typical one or two dwelling house in 1994 is then divided by the mean purchase price of a one or two dwelling home in the same year.

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[34] See section two for a further discussion.

[35] An independent report by The National Board of Housing, Building and Planning (2002) also supports the view of changes in the characteristic construction of the average one- or two dwelling building. More specifically, year by year changes in the ratio of construction costs per square meter over the Building Price Index (BPI) for a given year (denoted *standard*) during the 1990s indicates changes in the characteristic construction.

[36] Here I follow the approach of Emanuelsson (2015) and use the Factor Price Index (FPI) as a proxy for construction growth. The FPI excludes land costs in its construction which is important in this context. I use the FPI excluding wage drift and VAT for collectively built one-or two dwelling buildings. In contrast to the BPI which is an output index, the FPI is an input index and is therefore less sensitive to quality changes of housing over time.

[37] Construction cost data for the year 1993 is not available.

$$\sigma_m = \frac{(CC_{1994}/sqm) \times F_{1994}}{P_{1994,m}}$$

where, CC_{1994} is the nationwide net building cost per total primary utility floor space in 1994, F is the floor space measure and $P_{1994,m}$ is the average purchase price in 1994 for municipality m. In 1994 the average total primary utility floor space was 104.8 square meters and the average construction cost per square meter was 8921 SEK. This yields an average sigma of 1.57 for the sample of municipalities. This average is above one, implying that construction costs exceed the average purchasing price. Following the reasoning in Glaeser, Gyourko and Saiz (2008), this is not surprising given that the purchase price measures the appreciation on *existing* houses that sell, while the estimate of the construction costs are relevant for *new* houses. As the authors argue, such a bias is inevitable when any type of index is compared to new home construction costs. Nevertheless, "any positive gap between prices and production costs is a conservative measure of that difference".[38] On the other hand, from the perspective of Tobin's Q theory, it is possible that the higher σ_m, which is essentially the inverse of Tobin's Q, signals the unprofitability of construction. Both aspects should be taken into account when analyzing σ_m. The final price variable is defined as the difference in log prices net of the intercept ($\sigma_m \times \Delta \ln CC$).

6.2 Demand Shifters

Immigration

The immigration shock is defined as the difference in the number of foreign born population between 2003 and 1993 divided by the population share in 1993. Municipal level population data including the number of foreign born individuals for 1993 was retrieved from a historical publication by Statistics Sweden, since it is currently not available in the database.

Bartik Instrument

The raw data is taken from the RAMS database of Statistics Sweden for the years 1993 and 2003. The industry classification used is at the aggregate "letter combination level" of SNI92. At this level there are 11 groups.[39] The data includes the industry affiliation of all individuals of 16 years and older who work in the municipality. The Bartik instrument is constructed by multiplying industry employment shares for each municipality by the national growth rate of the corresponding industries (Glaeser, Gyourko and Saks, 2006). To avoid potential endogeneity which would arise if there is a feedback effect between municipality growth and national growth, an artificial national industry growth rate is used. For each municipality, it is computed by estimating growth

[38] Glaeser, Gyourko and Saiz (2008) compare the OFHEO-based repeat sales index with estimates of production costs for new houses.
[39] See Appendix II for a list of the industries.

over the period 1993-2003 for each industry, excluding the own municipality.[40] This is done for all municipalities. The Bartik instrument for municipality *m* is given by the sum of the employment share of industry *i*, in municipality *m,* in 1993 multiplied by the national growth rate of industry *i* over the period 1993-2003. Hence, the instrument yields an estimate of predicted employment growth stemming from nationwide industry growth, based on the industry composition of the municipality in 1993.

$$Bartik_m = \sum_i \frac{L_{m,i,1993}}{L_{m,1993}} \times G_{i,N-m}$$

where $L_{m,i,1993}$ is the employment in industry *i*, in municipality *m*, in 1993, $L_{m,1993}$ is total employment in municipality *m*, and $G_{i,N-m}$ is the growth of industry *i* for all municipalities except municipality *m.*

Climate and Regional Variables

Data on the average duration of sunlight (hours) in January was retrieved from the STRÅNG database of the Swedish Meteorological and Hydrological Institute (SMHI).[41] STRÅNG is a solar radiation model that provides data on a variety of radiation variables for any coordinate on a 11x11 km resolution (22x22 km resolution before 2006) starting in 1999. An average of the hours of sunshine duration in January for the period 1999-2003 was calculated by using the coordinates of the center point of each municipality, as defined in section four. As an alternative measure of weather conditions, I also retrieve the mean January temperature from the Diva GIS portal WorldClim. This data is then matched with data on coordinates of municipality center points. The WorldClim data is highly accurate, in that it provides mean temperatures over a long time period, and at a high spatial resolution.

To model regional fixed effects, and given the small sample a crude regional division is used, dividing the country into three parts. Each municipality falls within the region north, mid-regions or south.[42] For robustness, an alternative regional classification is used as well. The county regions at the highest level of aggregation[43] correspond quite closely to the former classification but not entirely. Coastal dummies are defined as those municipalities that have a border to the ocean using the maps of the Swedish Mapping, Cadastral and Land Registration Authority.

Table 12 displays summary statistics of the demand shifters. In general, national industry growth rates have a large impact on the overall employment growth of municipalities, with a large dispersion across municipalities. While employment growth

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[40] In practice this feedback effect, if existing, is small because the impact of each municipality on the national growth rate is small given the large number of municipalities, Stockholm being the possible exception.
[41] STRÅNG data used here are from the Swedish Meteorological and Hydrological Institute (SMHI), and were produced with support from the Swedish Radiation Protection Authority and the Swedish Environmental Agency.
[42] Swedish "lands classification": Norrland, Svealand, Götaland.
[43] County regions I, II, II.

was close to 13 percent in the top ten municipalities it is less than half that in the bottom ten. The average immigration shock is smaller. Note however, that the shock is proportional to the overall population level of the municipality. The average January temperature is -3.5 degrees, but is considerably lower in the lower percentiles. By contrast, the average sunshine duration in January, exhibits a much smaller variation, despite a known large variation in hours of daylight (sunset-sunrise). It is possible that extensive cloud formation acts to offset the variation in the number of daylight hours across municipalities, since the STRÅNG model also takes into account cloud and surface data in the estimation of hours of sunshine duration. Further, given that the average sunshine duration only covers four years, extreme values can have an impact on the result. Given these limitations, the average January temperature may act as a better proxy of weather related amenities. Overall, the demand shifters exhibit considerable variation across municipalities, with sunshine duration being the exception.

TABLE 12

Summary Statistics of Demand Shifters, 1993-2003

	Bartik employment growth (%)	Immigration shock (%)	Average January temperature (°C)	Average sunshine duration in January (hours)
Mean	8.89	1.76	-3.5	9.43
Std.dev.	2.64	2.07	3.1	0.27
10th	6.14	-0.46	-8.7	9.22
25th	6.84	0.49	-3.7	9.40
50th	8.38	1.63	-2.7	9.43
75th	10.65	2.55	-2.1	9.50
90th	12.75	4.31	-0.5	9.58

Notes: Sample of 109 municipalities

As a preliminary check of instrument strength the correlation between the Bartik instrument, immigration shock, average January temperature and average January sunshine duration is displayed in Table 13. The table shows that all the demand shifters except sunshine duration exhibit a relatively high level of correlation with the change in log supply. Motivated by this, the first three demand shifters are explored as candidate instruments in the next section.

TABLE 13

Correlation between Housing Supply and Demand Shifters, 1993-2003

	Log housing supply	Bartik instrument	Immigration shock	Average January temperature	Average January sunshine duration
Log housing supply	1.000				
Bartik instrument	0.623	1.000			
Immigration shock	0.460	0.412	1.000		
Average January temperature	0.295	0.120	0.417	1.000	
Average January sunshine duration	-0.0681	-0.0975	-0.0158	0.166	1.000

Notes: Sample of 109 municipalities

7 RESULTS

This section is structured as follows. First, I provide support for the suitability of the chosen instruments in the Swedish context, assessing the strength of the first stage and evaluating threats to the exclusion restriction by employing the Sargan-Basmann Chi-square test. In the section that proceeds, results of 2SLS estimation of the baseline regression are presented and a tentative estimate of the average housing supply elasticity is provided. The role of geographic constraints is assessed by including the measure of undevelopable land previously constructed in an extension of the baseline regression. Finally, in the last section I assess the robustness of the results.

7.1 Instrument Strength and the First Stage

The results of the first stage regression are presented in Table 14. All instruments are individually significant at the 10 percent level of significance, although the small magnitude of the coefficient of the average January temperature suggests climate amenities to be of smaller importance compared to the other two instruments. The test for joint significance of the instruments yields an F-statistic of 22.57, which is above the 5 percent critical value of 13.91 (Stock et al., 2005). Hence, the instruments can be regarded as relevant and not weak. Furthermore, the F-statistic of different combinations of the instruments, as well as the statistic associated with single instruments, always allow for a rejection of the null hypothesis of weak instruments. In the main specification the Swedish "lands" are used to control for regional fixed effects, but the results are not sensitive to a different choice of regional fixed effects.[44] In general, the dissimilarity of instruments in the sense that the Bartik instrument, average January temperature and immigration shock capture different aspects of demand shocks, should act to increase the power of the test.[45] This issue will be explored further by employing a test for over-identifying restrictions in the proceeding section.

[44] If instead the Swedish county regions are used as regional fixed effects, the Bartik instrument, immigration shock and average January temperature are all individually and jointly statistically significant at the 5 percent level of significance, with an F-statistic of 21.25.
[45] See for instance the discussion in Combes and Gobillon (2014).

TABLE 14
First-Stage Regression of Housing Supply

	ΔLog(Housing supply)
Bartik instrument	0.536***
	(0.123)
Immigration shock	0.337***
	(0.124)
Average January temperature	0.00230*
	(0.00121)
Observations	109
F-statistic (Prob > F)	22.57

Notes: Sample of 109 municipalities. Robust standard errors are shown in parenthesis. The regression also includes regional fixed effects (Norrland, Svealand, Götaland). The F-statistic is from an F-test of the coefficients of all instruments being equal to zero.*** p<0.01, ** p<0.05, * p<0.1

7.2 Average Housing Supply Elasticity and the Second Stage

The strong first stage of the previous section suggests that the Bartik instrument, immigration shock and average January temperature can be used as instruments for the housing supply. Hence, to consistently estimate housing supply elasticities, the difference in the log of the price variable, adjusted for construction costs, is regressed on the difference in log housing supply which is instrumented for using the demand shifters with 2SLS. In this setting, instrument exogeneity can be evaluated by testing the over-identifying restrictions of the model, given the availability of multiple instruments. The instruments pass the Sargan's (1958) and Basmann's (1960) Chi-squared test with a p-value of 0.3372, implying that the null hypothesis of any of the instruments being exogenous cannot be rejected at any conventional level of significance.

Table 15, column (1), reports the results from an OLS estimation of the baseline regression (1) of section five. Although this estimation yields biased estimates, it is useful to include for comparison to the 2SLS estimation and for assessing the magnitude of the bias.

Column (2) reports the results from estimating the baseline regression using 2SLS. The slope coefficient of $\Delta\log(Q)$, which denotes the instrumented housing supply, yields an estimate of the average inverse housing supply elasticity. The estimate is highly statistically significant, and implies an average housing supply elasticity of 0.0784 (1/12.754). It is considerably lower than the OLS estimate of 0.166 (1/6.030) suggesting a large bias in the OLS estimate. This is expected, given that price is simultaneously determined in this supply and demand setting.

The elasticity estimate of 0.0784 implies that the average housing stock increases on average by less than 1 percent when prices increase by roughly 10 percent. This is a very low elasticity, in particular when compared to the estimates in the American literature and the corresponding estimate of Saiz (2010), which was approximately 1.54 (1/0.650), but correspond well to the notion of an unresponsive housing supply in Sweden. In particular, the median supply elasticity found by Ho (2015) for her sample of around 150 municipalities was 0.10. Important to note, the estimated elasticity is robust to any combination of the choice of instruments, as well as using a single instrument. All specifications yield statistically significant and similar estimates of the average inverse supply elasticity.[46]

In column (3) the role of geography as a determinant of the elasticity is explored by the inclusion of the interaction term of undevelopable land and instrumented housing supply. Contrary to what is expected, the coefficient of the interaction term is negative. However, the coefficient is statistically insignificant, suggesting that geography does not play a role in explaining housing supply elasticities. For robustness, alternative measures of undevelopable land based on a 7 km, 11 km and 13 km radius were used as well. The coefficient on undevelopable land remains statistically insignificant.

Finally, in column (4) the specification includes the coastal dummy interacted with the instrumented housing supply. The coefficient of the measure of undevelopable land remains statistically insignificant and so does the coefficient of the coastal dummy. Hence, according to the results there is no support for the view that coastal markets have a more inelastic housing supply.

Overall, the results suggest 1) a significant bias associated with OLS estimation, 2) a very low elasticity of housing supply (2SLS), 3) no effect of geographic constraints as measured by the undevelopable land measure, on the housing supply elasticity, 4) no effect of being coastal on the housing supply elasticity. While the first null hypothesis of section five can be rejected, the second one cannot be rejected.

TABLE 15

2SLS Second-Stage of House Price Growth on Housing Supply and Undevelopable Land

	$\Delta\log(P)\ (supply)$: 1993 − 2003			
	(OLS)	(2SLS)	(2SLS)	(2SLS)
	(1)	(2)	(3)	(4)
Δlog(Q)	6.030***	12.754***	13.609***	12.710***
	(0.621)	(1.564)	(2.016)	(1.753)
Unavailable land × Δlog(Q)			-2.954	-6.319
			(3.706)	(4.435)
Coastal × Δlog(Q)				2.875
				(2.231)
Götaland	0.284***	0.181***	0.185***	0.208***
	(0.0646)	(0.0660)	(0.0663)	(0.0641)
Svealand	0.280***	0.0679	0.0628	0.0946
	(0.0727)	(0.0682)	(0.0675)	(0.0659)
Constant	-0.232***	-0.303***	-0.306***	-0.309***
	(0.0568)	(0.0543)	(0.0544)	(0.0537)

Notes: Sample of 109 municipalities. Q denotes the instrumented log housing supply, where the instruments used are the Bartik instrument, immigration shock and average January temperature. Robust standard errors in parenthesis. All specifications include regional fixed effects according to the Swedish “lands” classification (Norrland, Svealand, Götaland).Undevelopable land estimated using a 5 km radius. *** p<0.01, ** p<0.05, * p<0.1

[46] The average inverse elasticity of supply ranges from 12.257 to 15.926 for all possible combinations of the instruments, all of which are statistically significant at the 1 percent level.

7.3 Robustness Checks

In the this section I investigate the sensitivity of the results in section 7.2 to the classification system used by first considering a slightly different sample of municipalities corresponding to another notion of urbanization based on population density. Next, I consider the sensitivity of the results to outliers. Finally, I relax the assumption of homogenous construction cost growth across municipalities.

A Different Notion of Urbanization

Are the results sensitive to the classification system?[47] For robustness, I use a slightly different set of municipalities by using a different notion of urbanization. Instead of defining the sample using the DEGURBA classification, I define the sample of municipalities by choosing those that have a central city with a population greater than 10 000. There were 108 such municipalities in 1993. Since population plays an important role in the degree of urbanization, this should also constitute a relevant sample. The key drawback of this definition is that it focuses on the level of urbanization of the central city and not the entire municipality. For this reason it was not used as the main classification rule. Nevertheless, given that the central city of a municipality constitutes a large part of the municipality, it could arguably still serve as a proxy for the overall level of urbanization in the municipality. In fact, the correlation between the two classification systems is high; 82 municipalities are common for the two classification systems.

For each of these municipalities a measure of undevelopable land is constructed with a radius of 5 km.[48] The F-statistic of the first stage of the Bartik instrument and the immigration shock is 21.26.[49] This indicates that the instruments are not weak. An estimation of (2) yields an inverse elasticity estimate of 11.01, which is similar to the result in Table 15. However, once again the inclusion of the interaction term of land unavailability and the instrumented housing supply indicate that geography plays no role.

Sensitivity to Outliers

In section four the exogeneity of the measure of undevelopable land was discussed. The municipality of Haninge was found to be an outlier—the fraction of undevelopable land amount to almost 93 percent, while the next most constrained municipality has a fraction of approximately 71 percent. I perform the same estimation procedure as above,

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[47] The sensitivity of the results to the geographic scale can be important in housing markets given their high level of integration; see for instance Hilber and Vermeulen (2015).

[48] This table is not included in the appendix but is available upon request.

[49] Given that the Bartik instrument and immigration shock serve as strong instruments, and because section 7.1 revealed that the results were not sensitive to different combinations of the instruments, here I resort to only using the Bartik instrument and the immigration shock. The instruments pass the Sargan's (1958) and Basmann's (1960) Chi-squared test with a p-value of 0.8708.

excluding the municipality of Haninge. The F-statistic of the first stage of the Bartik instrument, immigration shock and average January temperature is 21.26. The estimate of the average inverse housing supply elasticity is approximately 12.86 and is statistically significant at all conventional levels of significance. The interaction of undevelopable land and housing supply remains statistically insignificant. Furthermore, the instruments pass the Sargan's (1958) and Basmann's (1960) Chi-squared test with a p-value of 0.3321. Moreover, I re-estimate the regressions excluding the top five municipalities. The results are robust to these changes—the average inverse housing supply elasticity is in this case 12.98 and statistically significant at the 1 percent level of significance. Finally, I also exclude the capital city Stockholm from the sample. The average inverse elasticity is then 12.09 and statistically significant at the 1 percent level of significance. This lower inverse elasticity implies a slightly higher elasticity of 0.08 when excluding Stockholm. Overall, the results found in section 7.2 do not appear to be sensitive to outliers.

Additional Robustness Checks

The previous analysis was based on the assumption that the growth of construction costs does not differ considerably between municipalities. Because data on construction costs indeed indicate regional differences, here I attempt to relax this assumption by using an alternative (regional) measure of construction costs. There are two main drawbacks of this approach. First, this growth variable will not take into account differences in the quality or characteristic of constructed houses. As the previous section indicated, quality improvements appear to have been important during the period. Second, data on construction costs does not exist on a municipal basis, but at a higher level of aggregation, giving only a crude indication of regional cost dispersion.

The alternative construction cost measure is constructed as follows. As construction costs I use the net building cost per total primary utility floor space in square meters for newly constructed conventional collectively built one- or two dwelling buildings in 1994 for each of the following regions: each of the three county regions as well as Greater Stockholm, Greater Göteborg, and Greater Malmö. The costs are calculated with deduction for subsidies. As previously I account for changes in the average size of the house. To calculate the construction cost associated with the average one- or two dwelling building, the net cost is multiplied by the average total primary utility floor space for each of the six regions. With the corresponding figure for 2003, the growth is constructed as the log difference in construction costs, deflated by the PPI.

Table 16 provides summary statistics of average house size and construction costs. Houses are generally, at least in terms of total floor utility space, larger in Greater-Malmö. The average house size is larger in all regions in 2003 compared to 1994, suggesting that it may be an important factor to take into account when comparing average house prices and the associated average construction costs. Further, the increase in the average size varies, with county region II experiencing the largest percentage increase over the period. Construction costs increased by a large margin in all regions with Greater-Stockholm experiencing the largest increase. The last column reports the average of sigma, σ_m by county. The average σ_m is in all cases above 1, indicating that construction costs in 1994 are higher than average purchase prices in the same year. Reasons for this were previously discussed. The important message from Table 16 is that regional differences in construction are large.

TABLE 16
Regional Differences in Average House Size, Construction Costs, and σ_m

	Total primary utility floor space per dwelling, square meters		Building cost/total primary utility floor space, SEK		Construction cost growth (%)	σ_m
	1994	2003	1994	2003	1994-2003	1994
Greater Stockholm	108.4	125.7	9 694	17 789	90.389	1.062
Greater Göteborg	103.6	112.6	8 773	14 311	58.631	1.145
Greater Malmö	110.8	130.0	8 464	14 560	80.582	1.500
County region I	83.3	107.0	8 842	12 281	59.628	1.534
Country region II	98.6	127.8	8 082	12 768	83.208	1.559
County region III	105.4	125.3	8 747	12 496	51.953	1.832

The results are sensitive to this alternative construction cost variable and this should be kept in mind when analyzing the elasticity estimate from section 7.2. The average inverse elasticity increases to 17.203, and is statistically significant at the 1 percent level of significance. The interaction of undevelopable land and housing supply remains statistically insignificant.

8 DISCUSSION AND CONCLUSION

This section is structured as follows. First, the estimate of the average elasticity of housing supply found in section seven is discussed and benchmarked against the estimates of other studies. This is followed by a discussion of potential reasons for the statistical insignificance of undevelopable land. Finally, the internal and external validity of the current study is evaluated.

8.1 The Average Housing Supply Elasticity

The previous section reported a housing supply elasticity estimate of approximately 0.078. This suggests a very low responsiveness of the housing supply; for every 10 percent increase in house prices the housing supply increases by less than one percent. Moreover, it stands in contrast to the findings of Caldera-Sanchez and Johansson (2013); their estimates implied a relatively elastic housing supply. However, this relatively high elasticity has been questioned (SOU 2015:48) as it corresponds little to the notion of a low elasticity of supply in Sweden. One possible reason for the high estimate is that Caldera-Sanchez and Johansson's analysis is based on the period 1980-2005 and during the late 1980s construction was high. Construction has since been low.

On the other hand, the estimate found in this study is close to the median housing supply elasticity of 0.10 found in Ho (2015) and conforms well to the notion of a low elasticity in Sweden (Englund, 2011). A simple comparison with the descriptive statistics of section five can be of use here to assess the reliability of the results. For the sample of 109 municipalities for the period 1993-2003, the average real price increase was approximately 54.1 percent, while the average supply increase was roughly 3.1 percent. Taking the ratio of the two yields a descriptive elasticity of 0.0573 – this is very close to the empirically estimated elasticity of 0.0784, supporting the empirical design.

Nevertheless, the descriptive measure is even lower than the estimated elasticity. The final robustness check of section seven may provide some insight into why this may be the case. Somewhat relaxing the assumption of homogenous construction cost growth by using the construction cost growth of the country's six regions instead of an aggregate growth figure, resulted in a lower elasticity estimate of 0.0581 (1/17.2). This is virtually equivalent to the descriptive estimate.

Two implications appear from this discussion. First, there is support for the chosen instruments and the 2SLS estimation, since the estimated average housing supply elasticity is very close to that seen in reality. Second, the assumption of homogenous construction cost growth may lack support in the Swedish context. The discussion provided in the background section supports this; there is a concern that competition is lacking in the construction sector. Therefore, incorporating heterogeneous construction costs may be preferred in the Swedish case. Municipal level construction cost data were not available for this study, but given that the estimated elasticity appears to be sensitive to this, future studies should take this into account.

8.2 The Role of Geography

Given that Saiz (2010) found geography to be an important determinant of housing supply elasticities and several other studies have provided indications of similar findings, a discussion of the lack of significance of geography in the Swedish context is warranted. I provide three explanations that are grounded in the design of the study, economic theory and findings from related literature, and the institutional framework respectively.

The unit of interest in this study is the municipality. The definition of municipalities, however, emanates from administrative boundaries rather than from economic activity, although the two often may overlap. Therefore, the measure of undevelopable land constructed was also on a municipal basis. There are two important drawbacks of this choice and this was touched upon in section four. First, from a theoretical point of view, municipalities may contain multiple centers or more commonly one central dominating city and a few smaller ones. These smaller cities need not necessarily be located at the border of the central city, rendering the monocentric city assumption questionable. More specifically the problem that may arise is a skewed housing supply, with a high concentration of the stock in the central city but a non-negligible fraction in other cities. An indication of this was seen in section four; on average the central city held only 54 percent of the stock in 1990. It is probable that these shares changed over time; with urbanization the share of the stock in the central city could have become higher by 1993. The resulting measure of undevelopable land that uses the central city as its centroid captures much of the constraints of the central city and the surrounding area, but it is unlikely to capture constraints located at a distance far away from the central city. To the extent that the 5 km radius tends to fail to capture a large fraction of the municipal level housing stock, the measure of undevelopable land does not reflect *true* geographic constraints.

This is an important concern. As such, the statistically insignificant effect found in this study is best not interpreted as causal evidence for the absence of an effect of geography in Sweden. Rather it provides motivation for modified approaches for future research. Two possible alternatives exist here. First, the measure of undevelopable land constructed in this study could be used, basing the empirical analysis on the central cities themselves rather than on the municipalities. Data on housing stock and prices at the city level can be provided by Statistics Sweden for a fee. Such data was not available for this study.

Second, an alternative approach, resembling the reasoning in Rose (1989a) is to still use the municipality as the unit of analysis but attempt to capture a larger share of the housing stock by creating multiple circles of e.g. a 3 km radius around each city's centroid within the municipality. This could be done for the top three cities. A crucial issue is how to combine the three shares of undevelopable land into one municipal level measure, and more specifically how to weight each share. Importantly, the weights used should be identical across all municipalities since adaptation of the weights to any feature specific to the municipality will render the measure of undevelopable land endogenous. One possible, albeit simple, weighting rule is to use the size of the housing stock. The results from section four, Table 9, could provide guidance in the choice of such weights. As a crude example, the undevelopable share of the central city could be assigned a weight of 0.5 while the second and third largest cities are assigned the weights 0.3 and 0.2 respectively. If all cities are equally constrained, the weighting does not matter. If however, one of the cities is highly constrained while the others are not, the weighting produces a measure of undevelopable land that is smaller reflecting the possibility of the housing stock to expand in the less geographically constrained areas of the municipality. This would constitute a refinement of the measure of geographic constraints constructed in this study.

Still it may well be that the measure of undevelopable land constructed here captures a large fraction of the housing stock, in particular if other cities are located close to the central city. Assuming that the measure of undevelopable land constructed captures the majority the constraints facing the municipality, from an economic theory point of view, there may be reason to believe that geography plays a less important role in the Swedish context. As Saiz (2010) argues, "physical constraints may not be important until the level of development is high enough to render them binding." To capture heterogeneity in the effect of undevelopable land, Saiz (2010) also includes population; in more populated areas the impact of land availability should be greater. In the Swedish context, this is one possible explanation for the absence of an effect of geography. This is supported by the findings of Hilber and Vermeulen (2015) who find that the effect of undevelopable land is largely confined to highly urbanized areas for their sample of 353 local planning authorities in England.

On the other hand, Ho (2015) finds an impact on price growth of developed land. Furthermore, Oikarinen, Peltola, and Valtonen (2014) find that geography plays an important role in explaining the housing supply elasticity and posit that "the results indicate that even in a sparsely populated country with small cities and abundant reserve of developable land in close proximity to cities, the price elasticity of housing is significantly dependent on city size and geographic constraints, just as theory suggests." In light of this, it is not evident from an economic point of view, why an effect was not identified in the Swedish case.

From an institutional framework's point of view, it may be the case that the restrictive regulatory environment dominates as a potential factor affecting housing supply elasticities. The municipal planning process means that any land that hypothetically could be used for construction has to go through a lengthy planning process, which can be subject to appeals. True developable land is land that has gone through this process. From this perspective, at least in the short-run such land, also referred to as "buildable land" in the Swedish context, is what effectively constitutes developable land. This could break the intuitive link between geography and prices. As an example, many of the less populated municipalities, that according to the Housing Market Survey experience a housing shortage, may be constrained by regulation limiting the amount of "buildable" land although the amount of *geographically* developable land is vast. In a report on land availability and construction,[50] primarily focusing on the metropolitan area of Stockholm, the role of "buildable land" is explained using a similar argument. With a direct reference to Saiz (2010) the report states that to the extent that the planning process constrains the amount of "buildable land" and thereby the supply of housing, it also has an effect on house prices. Of course, empirically, using the amount of "buildable land" instead of the geographically determined land availability measure is more complicated, since it is likely to be endogenous to house prices.

8.3 Internal and External Validity

In evaluating the results of this study, it is useful to consider the aim and choices made at the outset. As evidenced by the literature review, research on regional housing supply elasticities outside of the US and the UK are limited. In fact, one of the main contributions of the paper by Oikarinen, Peltola, and Valtonen (2014) as stated by the authors themselves, was to provide such estimates for a "small sparsely populated country". Moreover, even within the literature on regional elasticities in the US, the choice of theoretical model and empirical strategy differ. It is therefore not clear which model, if any, is best suited to a land-abundant and sparsely populated country such as Sweden.[51] A discussion of the underpinnings of the theoretical model of Saiz (2010) and its fit to the Swedish context or the need for possible adaptations were abstracted from in this study, the underlying assumption being that the fundamentals of the model are not context-specific. Rather, at the outset the premise was a methodology that was given. The analysis instead concerned the adaptation of the measure of geographic constraints—using a 5 km radius as in Oikarinen et al. (2014)—and the empirical implementation. In interpreting the results, this should be taken into account—*given* the transferability of Saiz's theoretical model to the Swedish context the estimate of the average housing supply elasticity has the potential of being interpreted as causal, provided the identifying assumptions of the empirical model hold.

With this in mind, an evaluation of the internal validity of this study is here bound to a discussion of the validity of the empirical strategy. Four features of the empirical design support the internal validity. First, the instrumental variable approach used in this study makes use of instruments that have been argued suitable not only in Saiz (2010) but numerous other studies using simultaneous equations models (see for instance Saks, 2008; Huang and Tang, 2012; Paciorek, 2013). Still, this research is confined to the US. While the Bartik instrument is more of a theoretical construct, and climate variables may be interpreted in similar ways across countries, the suitability of the immigration shock instrument would benefit from a closer investigation in the Swedish context. Important to note, this study can and does establish a strong first stage—the instruments are indeed relevant. It is the more intricate issue of the

[50] Sweden's National Board of Housing, Building, and Planning (2015).

[51] Note that land abundance per se does not provide any insight into the magnitude of elasticities. Proponents of the local nature of housing supply would argue that local conditions, be it land availability or population, matter more than nationwide characteristics.

exclusion restriction that—as it cannot be formally proven—merits further attention. Still, the shape of the country produces large variation in various climate characteristics and future research could benefit from exploring other alternatives. This study found a correlation of 0.295 between log housing supply and the average January temperature. It is possible that other climate variable would yield a greater correlation. This would improve the efficiency of the 2SLS estimator. One possibility would be to explore variation in daylight during the winter or summer, as there are large differences between the north and the south.

Second, all possible combinations of the instruments, as well as the use of single instruments, yielded average housing supply elasticity estimates that were always statistically significant and very close in magnitude. This provides strong support to the average elasticity estimate found. Third, a test of the over-identifying restrictions of the model also provided support to the view that the instruments were exogenous. Finally, and perhaps most convincingly, the elasticity estimate found is very close in magnitude to the actual elasticity obtained by calculating the ratio of the change in the housing stock and house prices over the relevant time period. All in all, this provides support to the internal validity of the empirical design.

Still, one possible source of endogeneity in the Swedish case is related to the institutional framework. Many municipalities have municipal level companies or boards[52] that can supply housing. In contrast to the typical housing provider, municipal companies often have specific guidelines related to ensuring housing for different stakeholder groups in society including students and retirees. If municipalities with a large student population, typically municipalities with a university, have municipal companies that systematically supply housing to accommodate the housing needs for this specific population, there is reason to believe endogeniety arises. The reason for this is that the profitability condition presented in section five is now determined not only by construction and land costs but also by another variable such as the size of the student population, causing omitted variable bias. If then, in the empirical counterpart the size of the student population is omitted and it is correlated with a demand shifter such as immigration, and if immigration is particularly high in municipalities with a university, then the exclusion restriction of the immigration shock fails. However, in practice the supply of housing by municipal companies is extremely limited. Nevertheless this could be taken into account, and ideally the supply stock should be adjusted net of the supply of the municipal companies.

As a concluding note on internal validity, one potentially important lesson from the empirical exercise of this study, which was previously touched upon, is the assumption of homogenous construction costs. The sensitivity of the average elasticity estimate to the two different definitions of construction costs in this study directs attention to the construction sector in Sweden. Hence, while the assumption of homogenous construction costs in the American context may be justified, this study questions whether the same assumption is justifiable in the Swedish context.

[52] In Swedish: Allmännyttan.

Turning to issues pertaining to the external validity of this study, the estimated elasticity found is an average for the 109 municipalities that according to Eurostat's DEGURBA classification were classified as either densely populated areas or intermediate density areas. As such, it is not representative of the average elasticity estimate for the country as a whole. Since population density theoretically is viewed as a typical supply side constraint, limiting the responsiveness of the supply stock to adjust, there is reason to believe that the average elasticity estimate found in this paper is a lower bound to the aggregate estimate. From this perspective, the greater estimates found in Caldera-Sanchez and Johansson (2013) may be partly explained.

Another issue of external validity relates to time. To what extent is the average elasticity estimate found representative of the elasticity of supply today? As could be seen in the background section, two important policy changes affecting the construction sector took place just before the time period of this study, and importantly the period of this study was predated by a crisis. Nevertheless growth quickly picked up and has remained high since. The high levels of sigma found, defined as the ratio of the construction cost index to house prices for the baseline assumption of homogenous costs, was substantially above one during the period 1993-2003. Across the six regions it was also above one. Given that sigma is in practice the inverse of Tobin's Q, this gives a rough indication[53] of possible disincentives to produce. By contrast Tobin's Q has been well above one in recent years. This limits inference across time. However, apart from the construction cost factor, there is reason to believe that the underlying supply side constraints that affected the supply of housing during the period 1993-2003 still remain today.

[53] Given that the construction cost is not at the municipal level.

9 CONCLUSION

The aim of this study was to investigate the role of geography in explaining housing supply elasticities. To this end a measure of undevelopable land, defined as the fraction of land corresponding to water bodies, wetlands or steep-slope zones within a 5 km radius from city centroids, was constructed using ArcGIS. A sample of 109 municipalities over the time period 1993-2003 were analyzed. To consistently estimate the housing supply elasticity three demand shifters were identified as useful instruments; the Bartik instrument, an immigration shock and the average January temperature. An average elasticity parameter of approximately 0.078 was found. Geography could not explain the average housing supply elasticity estimated.

Several explanations were provided for the insignificance of geography. First, the measure of undevelopable land may not capture the entire housing stock if municipalities tend to have a skewed distribution of the housing stock in relation to the central city. As such, it may not give an accurate picture of the true geographic constraints facing the municipality. Second, it may be that urbanization is not yet at a level that will render geographic constraints binding. A counter-argument to this is that geography was found to play a role in another sparsely populated country with abundant land (Finland). Third, it is possible that features of the institutional framework break the link between geographically developable land and land that is rendered developable from a regulatory aspect.

From a policy point of view, this study provides a further indication of a very low responsiveness of housing supply in Sweden. Although the time frame of this study was confined to the years 1993-2003, the sharp growth of house prices and the small response of the housing stock since, as well as an institutional framework that is largely unchanged, suggests that the implication of this study—a low responsiveness of housing supply—may still well reflect the housing market today.

Future research would benefit from conducting the analysis of this study at the city-level instead of the municipal level, using the undevelopable land measure constructed here, as it is based on the centroid of the central city of the municipality. Alternatively, the municipal-level unit of analysis is maintained, but the measure of undevelopable land is adjusted to take into account the distribution of the housing stock in the municipality while retaining the exogeneity property.

Of particular interest is a study of the impact of regulation, given the attention it has received in the Swedish context. To date there exists no regulation index comparable to the Wharton Residential Urban Land Regulation Index in the US. Given the importance of understanding price variation across time and space in Sweden, the construction of such an index could potentially be very useful towards that end. The Housing Market Survey conducted by the National Board of Housing, Building, and Planning could be a potentially useful starting point for the construction of such an index. As of 2016, the authority also publishes a survey describing aspects of land use and regulation. This should provide particularly useful.

As Englund (2011) expresses it, understanding why housing supply has responded so modestly to rising house prices in Sweden should be a topic for further research. This thesis used the conceptual framework of regional price variation and housing supply elasticities used extensively by Glaeser, Gyourko and others, and the methodology of Saiz for a new perspective in Sweden on house price growth over time and across regions. Although the main focus was to study the role of geography within this framework, future research could benefit from conducting a similar analysis of regulation.

REFERENCES

A. BIBLIOGRAPHY

Agell, J., Englund, P. & Södersten, J. (1996). Tax Reform of the Century—the Swedish Experiment. *National Tax Journal*, 49(4), 643-664.

Baum-Snow, N. & Ferreira, F. (2015). Causal Inference in Urban and Regional Economics. In: Henderson, J.V., Duranton, G., Strange, W. (Eds.). *Handbook of Regional and Urban Economics* (vol 5, pp. 3-68). Amsterdam: North Holland.

Berg, L. (2002). Prices on the Second-Hand Market for Swedish Family Houses: Correlation, Causation and Determinants. *European Journal of Housing Policy,* 2(1), 1-24.

Berg, L. & Berger, T. (2006). The Q Theory and the Swedish Housing Market—An Empirical Test. *Journal of Real Estate Finance and Economics,* 33(4), 329-344.

SOU. (2015). Bostadsmarknaden och den ekonomiska utvecklingen. Statens Offentliga Utredningar 2015:48. Retrieved November 3, 2015, http://www.regeringen.se/contentassets/bdf96e86d579425581134dae37c1b3d2/lu-bilaga-3-hela-till-webben.pdf

Blackley, D.M. (1999). The Long-Run Elasticity of New Housing Supply in the United States: Empirical Evidence for 1950 to 1994. *Journal of Real Estate Finance and Economics,* 18(1), 25-42.

Blanchard, O.J., Katz, L.F., Hall, R.E. & Eichengreen, B. (1992). Regional Evolutions. *Brookings Papers on Economic Activity,* 1992(1), 1-75.

B0 41 SM 0401. (2003). Prices of Real Estate in 2003. Statistiska meddelanden, Statistics Sweden. Retrieved February 5, 2016, from http://www.scb.se/statistik/BO/BO0501/2003A01/BO0501_ 2003A01_SM_BO41SM0401.pdf

Brueckner, J.K. (1987). The Structure of Urban Equilibria: A Unified Treatment of the Muth-Mills Model. In: Mills, E.S. (Ed.). *Handbook of Regional and Urban Economics* (vol. 2, pp. 821-845). Amsterdam: North Holland.

Burchfield, M., Overman, H.G., Puga, D. & Turner, M.A. (2006). Causes of Sprawl: A Portrait from Space. *Quarterly Journal of Economics*, 121(2), 587-633.

Caldera-Sanchez, A. & Johansson, Å. (2013). The Price Responsiveness of Housing Supply in OECD Countries. *Journal of Housing Economics,* 22(3), 231-249.

Chakrabarti, R. & Zhang, J. (2015). Unaffordable Housing and Local Employment Growth: Evidence from California Municipalities. *Urban Studies,* 52(6), 1134-1151.

Combes, P., Duranton, G., Gobillon, L. & Roux, S. (2010). Estimating Agglomeration Economies with History, Geology, and Worker Effects. In: Glaeser, E.L. (Ed.), *Agglomeration Economics* (pp. 15-66). Chicago: University of Chicago Press.

Combes, P. & Gobillon, L. (2015). The Empirics of Agglomeration Economies. In: Henderson, J.V., Duranton, G., Strange, W. (Eds.). *Handbook of Regional and Urban Economics* (vol. 5, pp. 247-348). Amsterdam: North Holland.

Cox, W. (2011). Constraints on Housing Supply: Natural and Regulatory. *Econ Journal Watch,* 8(1), 13-27.

DiPasquale, D. & Wheaton, W.C. (1996). The Urban Land Market: Rents and Prices. In: *Urban Economics and Real Estate Markets* (pp. 35-59). Englewood Cliffs, NJ: Prentice Hall.

DiPasquale, D. & Wheaton, W.C. (1994). Housing Market Dynamics and the Future of Housing Prices. *Journal of Urban Economics,* 35(1), 1-27.

Emanuelsson, R. (2015). Utbudet av bostäder i Sverige. *Penning- och valutapolitik,* 2015:2, Sveriges Riksbank. Retrieved October 20, 2015, http://www.riksbank.se/Documents/ /Rapporter/POV/2015 /2015_2/rap_pov_artikel_3_150917_sve.pdf

Englund, P. (2011). Svenska huspriser i ett internationellt perspektiv. *Sveriges Riksbank,* Retrieved February 20, 2016, from http://www.riksbank.se/Upload/Rapporter /2011/RUTH /RUTH.pdf

Fischel, W.A. (2001). *The Homevoter Hypothesis: How Home Values Influence Local Government Taxation, School Finance, and Land-Use Policies*. Cambridge, MA and London, England: Harvard University Press.

Glaeser, E.L., Gyourko, J. & Saiz, A. (2008). Housing Supply and Housing Bubbles. *Journal of Urban Economics,* 64(2), 198-217.

Glaeser, E.L., Gyourko, J. & Saks, R.E. (2006). Urban Growth and Housing Supply. *Journal of Economic Geography,* 6(1), 71-89.

Glaeser, E.L., Kolko, J. & Saiz, A. (2001). Consumer City. *Journal of Economic Geography,* 1(1), 27-50.

Green, R.K., Malpezzi, S. & Mayo, S.K. (2005). Metropolitan-Specific Estimates of the Price Elasticity of Supply of Housing, and their Sources. *American Economic Review,* 95(2), 334-339.

Gyourko, J. (2009). Housing Supply. *Annual Review of Economics,* 1(1), 295-318.

Gyourko, J., Saiz, A. & Summers, A. (2008). A New Measure of the Local Regulatory Environment for Housing Markets: The Wharton Residential Land Use Regulatory Index. *Urban Studies,* 45(3), 693-729.

Harter-Dreiman, M. (2004). Drawing Inferences about Housing Supply Elasticity from House Price Responses to Income Shocks. *Journal of Urban Economics,* 55(2), 316-337.

Hilber, C.A. & Vermeulen, W. (2015). The Impact of Supply Constraints on House Prices in England. CPB Netherlands Bureau for Economic Policy Analysis (No. 219).

Ho, G. (2015). Housing Supply Constraints in Sweden. IMF Country Report No. 15/330. Retrieved January 13, 2016, from https://www.imf.org/external/pubs/ft/ scr/2015/cr15330.pdf

Hort, K. (1998). The Determinants of Urban House Price Fluctuations in Sweden 1968–1994. *Journal of Housing Economics,* 7(2), 93-120.

Huang, H. & Tang, Y. (2012). Residential Land Use Regulation and the US Housing Price Cycle between 2000 and 2009. *Journal of Urban Economics,* 71(1), 93-99.

Hüfner, F. & Lundsgaard, J. (2007). The Swedish Housing Market: Better Allocation via Less Regulation. OECD *Economics Department Working Papers,* No. 559, OECD Publishing. http://dx.doi.org/10.1787/175230504175

Ihlanfeldt, K. & Mayock, T. (2014). Housing Bubbles and Busts: The Role of Supply Elasticity. *Land Economics,* 90(1), 79-99.

Lind, H. (2002). Ds 2003: 006 Bostadsbyggandets hinderbana. Retrieved October 15, 2015, from http://eso.expertgrupp.se/wp-content/uploads/2013/08/2003_6-Bostadsbyggandets-hinderbana.pdf

——. (2003). Rent Regulation: A Conceptual and Comparative Analysis. *European Journal of Housing Policy,* 1(1), 41-57.

——. (2012). Den svenska debatten om bostadsmarknaden. [The Swedish Debate on the Housing Market]. *Kart og Plan*, 72(2), 86-94.

Malpezzi, S., Chun, G.H. & Green, R.K. (1998). New Place-to-Place Housing Price Indexes for US Metropolitan Areas, and their Determinants. *Real Estate Economics,* 26(2), 235-274.

Mian, A., Sufi, A. (2014). *House of Debt.* Chicago: University of Chicago Press.

Notowidigdo, M.J. (2011). The Incidence of Local Labor Demand Shocks. NBER Working Paper No. 17167.

Oikarinen, E., Peltola, R. & Valtonen, E. (2015). Regional Variation in the Elasticity of Supply of Housing, and its Determinants: The Case of a Small Sparsely Populated Country. *Regional Science and Urban Economics,* 50, 18-30.

Öster, A. & Agell, J. (2007). Crime and Unemployment in Turbulent Times. *Journal of the European Economic Association,* 5(4), 752-775.

Paciorek, A. (2013). Supply Constraints and Housing Market Dynamics. *Journal of Urban Economics,* 77(1), 11-26.

Rappaport, J. (2007). Moving to Nice Weather. *Regional Science and Urban Economics,* 37(3), 375-398.

Rose, L.A. (1989a). Topographical Constraints and Urban Land Supply Indexes. *Journal of Urban Economics,* 26(3), 335-347.

——. (1989b). Urban Land Supply: Natural and Contrived Restrictions. *Journal of Urban Economics,* 25(3), 325-345.

Rosenthal, S.S. & Strange, W.C. (2008). The Attenuation of Human Capital Spillovers. *Journal of Urban Economics,* 64(2), 373-389.

Saiz, A. (2008). On Local Housing Supply Elasticity. Mimeo. The Wharton School, University of Pennsylvania.

——. (2010). The Geographic Determinants of Housing Supply. *Quarterly Journal of Economics,* 125(3), 1253-1296.

Saks, R.E. (2008). Job Creation and Housing Construction: Constraints on Metropolitan Area Employment Growth. *Journal of Urban Economics,* 64(1), 178-195.

Statistics Sweden. (2012). Varannan svensk bor nära havet. *Välfärd*, 2, 10-12. Retrieved March 20, 2016, from http://www.scb.se/sv_/Hitta-statistik/Artiklar/Varannan-svensk-bor-nara-havet/

Sweden's National Board of Housing, Building and Planning. (2002). Bostadsbyggandet och byggkostnaderna åren 1960-1990. Boverket Januari 2002. Retrieved February 1, 2016 from http://www.boverket.se/globalassets/publikationer/dokument/2002/bostadsbyggandet_och_byggkostnaderna_aren_1960_till_1999.pdf

Sweden's National Board of Housing, Building and Planning. (2015). Land Prices, Land Shortage and Construction. [Markpriser, markbrist och byggande]. Market Report March 2015. Retrieved November 3, 2015, from http://www.boverket.se/globalassets/publikationer/dokument/2015/marknadsrapport-mars-20151.pdf

Sørensen, P.B. (2013). The Swedish Housing Market: Trends and Risks. *Rapport till Finanspolitiska rådet.* Retrieved March 3, 2016, from http://www.finanspolitiskaradet.se/download/18.11165b2c13cf48416debd71/1420730439471/Underlagsrapport+2013-5+S%C3%B6rensen.pdf

Tobin, J. (1969). A General Equilibrium Approach to Monetary Theory. *Journal of Money, Credit and Banking,* 1(1), 15-29.

Vermeulen, W. & Rouwendal, J. (2007). Housing Supply and Land Use Regulation in the Netherlands. Tinbergen Institute Discussion Paper, TI 2007-058/3.

Wheaton, W.C., Chervachidze, S. & Nechayev, G. (2014). Error Correction Models of MSA Housing Supply Elasticities: Implications for Price Recovery. MIT Department of Economics Working Paper No. 14-05.

Wilhelmsson, M. (2008). Regional House Prices: An Application of a Two-Equation Model to the Swedish Housing Market. *International Journal of Housing Markets and Analysis,* 1(1), 33-51.

Wooldridge, Jeffrey M. (2009). Simultaneous Equations Models. In: *Introductory Econometrics: A Modern Approach* (4th edition) (pp. 546-567). Mason, OH: South-Western Cengage Learning.

B. INTERNET SOURCES

Eurostat. Degree of Urbanisation, Methodology. Retrieved October 20, 2015, from http://ec.europa. eu/eurostat/web/degree-of-urbanisation/methodology

Statistics Sweden. Statistikatlas – Småhuspriser. Retrieved April 15, 2016, from http://www.scb.se/Kartor/Statistikatlas_KN_201404/index.html#story=5

Sweden's National Board of Housing, Building and Planning. (2003). The Housing Market Survey (2003, 2013, 2015, 2016). Retrieved May 13, 2016, from http://www.boverket.se/sv/om-boverket/publicerat-av-boverket/oppna-data/bostadsmarknadsenkaten/

United States Census Bureau. Metropolitan and Micropolitan Statistical Areas Main. Retrieved February 1, 2016, from http://www.census.gov/population/metro/

APPENDIX

Appendix I: Constructing a Measure of Undevelopable Land

In the first step, elevation maps (see Figure 3) were used to identify areas with a slope above 15 percent (see Figure 4, areas with a slope above 15 percent relative to neighboring grid cells are colored in red). The white borders in the figures below represent municipal boundaries. The black circle is the location of the central train station of Fagersta municipality. Recall that the geographic centroid of a polygon, defined by the area of the central city within the municipality, is estimated as an alternative if a central train station does not exist. In the second step, a buffer is created around the centroid with a 5 km radius as the benchmark (see Figure 5). The area corresponding to steep-slope zones, water bodies and wetlands (also colored in blue) as a share of the area of the circle is then calculated (see Figure 6). This gives a measure of undevelopable land.

FIGURE 3
Elevation Map of Fagersta Municipality

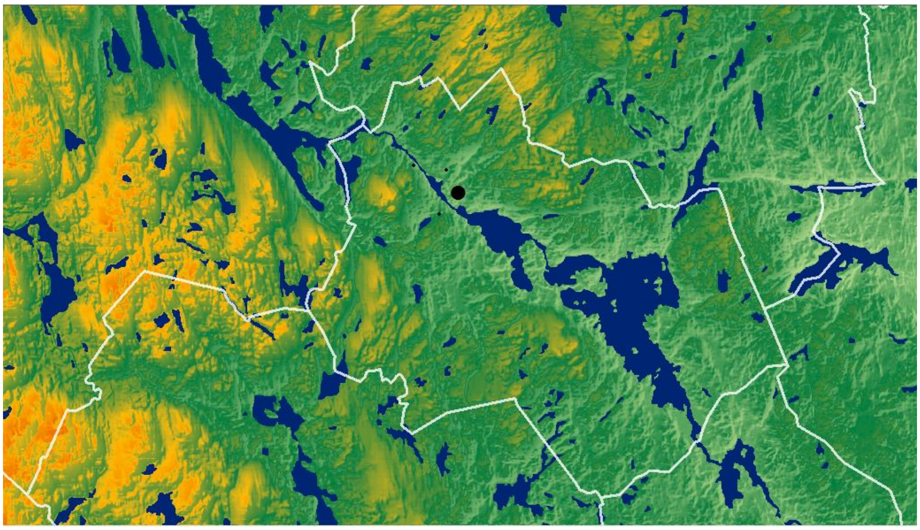


FIGURE 4
Area with a Slope above 15 percent

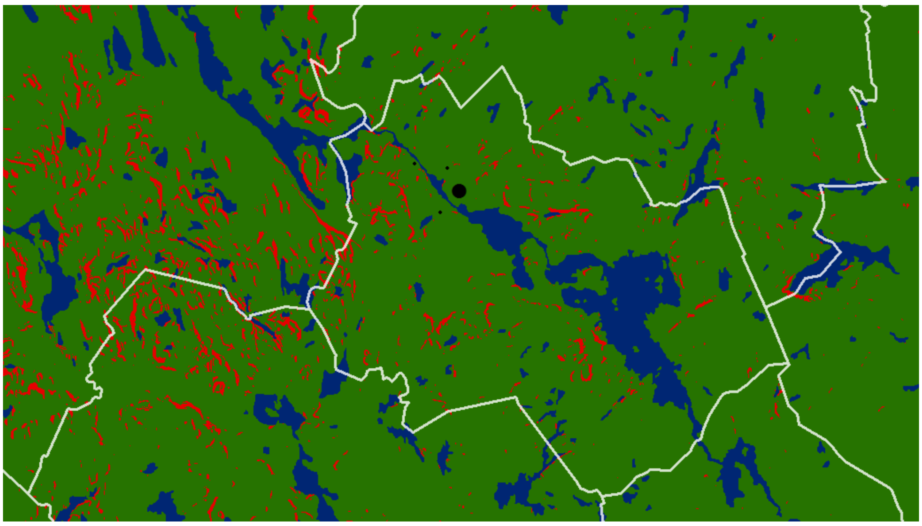


FIGURE 5

Buffer around the Train Station/Centroid (5 km Radius)

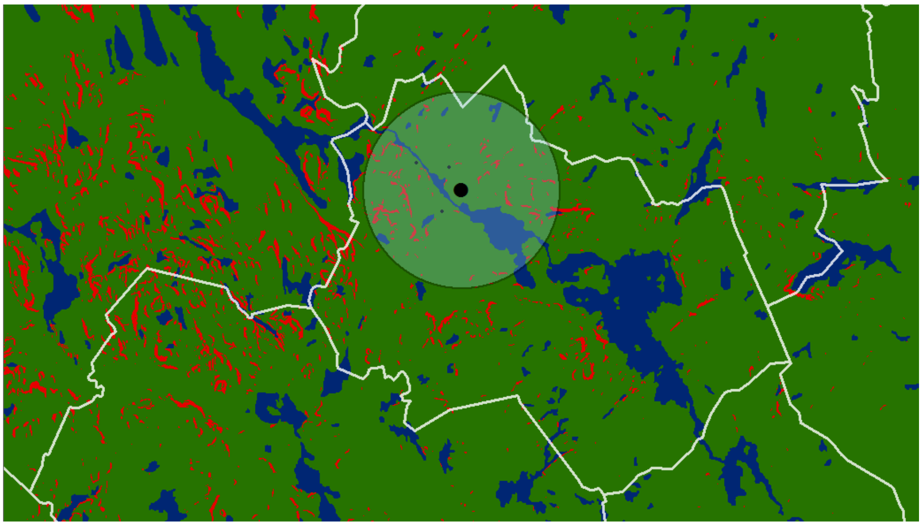
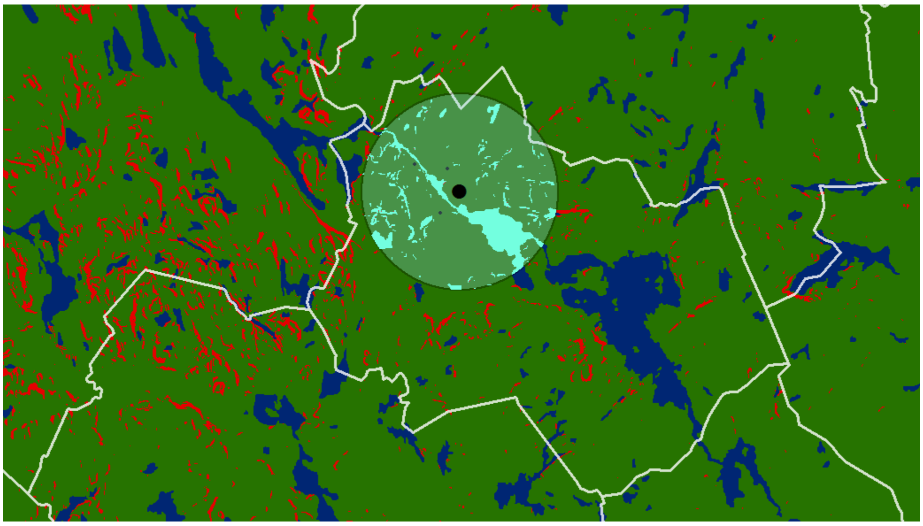


FIGURE 6

Share of Undevelopable Land



Appendix II: Data Appendix

Variable	Source	Description
Housing stock		
Number of one and two dwelling buildings (1993, 2003)	Statistics Sweden	For the period 1991-2009, Statistics Sweden projects the housing stock by using the housing stock reported in the Census of Population and Housing in 1990 as a base, adding yearly changes in new construction. Changes that are not taken into account include conversions from dwellings for seasonal and secondary use into one/two dwelling buildings and vice versa. Most demolitions of one and two dwelling buildings are also not considered.
House prices		
Unweighted purchase price coefficient for one and two dwelling buildings (1993, 2003)	Statistics Sweden	
Change of assessed value for one and two dwelling buildings for permanent living at the general assessment of real estate in 1996 by region, unweighted change		
Change of assessed value for one and two dwelling buildings for permanent living at the general assessment of real estate in 2003 by region, unweighted change	Statistics Sweden	
Consumer Price Index, total, Shadow Index numbers (1993, 2003)	Statistics Sweden	
Average purchase price for one and two dwelling buildings (1994)		Used for construction of the municipal-specific intercept σ_m
	Statistics Sweden	
Construction costs		
Net building costs per total primary utility floor space, SEK (1994)	Statistics Sweden	
Average total utility floor space, sqm (1994)	Statistics Sweden	
Factor price index excluding wage drift and VAT for collectively built one and two dwelling buildings (1994, 2003)	Statistics Sweden	
Producer price index by products SPIN 2007, A-E: Products of agriculture, forestry and fishing; mining and quarrying; manufactured products; electricity; gas; heating; cooling; water	Statistics Sweden	

Data Appendix (continued)

Variable	Source	Description
Bartik instrument		
Number of employed 16+ years by region of residence industry SNI92 (RAMS) (1993-2003)	Statistics Sweden	11 industry groups: A+B Agriculture, forestry, hunting and fishing; C+D Mining, quarrying and manufacturing; E+90 Electricity, gas and water supply, refuse disposal; F Construction industry; G+I Wholesale and retail trade, transport, storage and warehousing, post and telecommunications; H+O excl. 90 + P Personal and cultural service activities; J + K excl. 73 Financial institutions, real estate activities, business activities; L+Q Public authorities, national defense, extra-territorial organizations; M+73 Research and development, education; N Health and social work establishments, 00 Major groups missing
Immigration shock		
Population (1993, 2003)	Statistics Sweden	
Foreign born persons by region (2003)	Statistics Sweden	
Foreign born persons by municipality (1993)	Statistics Sweden	The data is not available in the Statistics Sweden database, but in the publication "Population Statistics 1993, Part 3 Distribution by sex, age and citizenship etc"
Climate and regional variables		
Average January temperature, Celsius (1950-2000)	WorldClim	Global Climate Data, ESRI Grids (ArcGIS data) http://www.worldclim.org/current
Average sunshine duration in hours (1999-2003)	STRÅNG Database	The coordinates of the central railway station/centroid are used as reference point. http://strang.smhi.se/extraction/index.php
Regional classifications		
DEGURBA	Statistics Sweden Eurostat	http://ec.europa.eu/eurostat/ramon/miscellaneous/index.cfm?TargetUrl=DSP_DEGURBA Also see the publication: "Regional divisions in Sweden on 1 January 2015" by Statistics Sweden
Other variables		
Median income per person (SEK), 31/12 (1993, 2003)	Statistics Sweden	
Share of adult population with post-secondary education of at least 3 years, excluding post-graduate studies (2003)	Statistics Sweden	
Distribution of the housing stock (one and two dwelling buildings) by municipality, by city (1990)	Statistics Sweden	The data is not available in the Statistics Sweden database, but in the publication "Population and Housing Census 1990, Part 3 Dwellings"