[Re] A New Approach to Estimating the Production Function for Housing

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A reference implementation of:

Epple, Dennis, Brett Gordon, and Holger Sieg. 2010. *“A New Approach to Estimating the Production Function for Housing.”* American Economic Review, 100 (3): 905-24.DOI: 10.1257/aer.100.3.905

# Introduction

The purpose of the paper is to do a replication of the paper “A New Approach to Estimating the Production Function for Housing” (Epple, Gordon, and Sieg [2010](#ref-epple2010new)) that estimates the production function for housing. Based on two factors - the observed variation in land prices and housing values per unit of land, the original paper has provided an algorithm to identify the housing supply function per unit of land. This in turn is used to derive an estimate of the underlying production function. The approach yielded plausible estimates for the price elasticity of housing supply per unit of land, based on data from Allegheny County in Pennsylvania. In the paper,we propose a reference implementation by adding two additional models to replicate an estimation function that relates land price and home value per unit land and produce the corresponding tables and plots.Estimating housing production functions is challenging, as the quantity and price per unit of the housing services are not observed by the econometrician. Replicating the study helps us to understand how the underlying production function is estimated by treating prices and quantities of housing services as latent variables, without relying on strong functional form assumptions.

# Methods

The current methodology provided by the author for estimating house price supply function uses parametric models. The author in the paper aims to establish a function which relates land price and home value per unit land . The parametric functions used for the purpose is OLS with different variations in it. The paper has used multiple transformation on data to produce linear, log linear and polynomial linear models to best identify the relation.

Since, the function forms the root of further analysis and calculation, it is imperative that we replicate the study of these models to test the robustness and the assumptions behind the models. We decided to split the method of implementation in two direction. The first method is to use a different model for replication and the other is changing the loss function used in the model.

For the first case of different model, we decided to use Generalized Linear Model with different distribution families. Using different families allows us to verify the condition of normality of error in the models used by authors. We noticed that the gaussian distribution family with log independent and dependent variable produced a line that fitted the best with the data and the corresponding coefficients were very similar to the log linear model used by the author.

In the case of different loss function, we wrote a function code to implement log linear regression with gradient descent loss function. The gradient descent loss function provides a more flexible approach because of the presence of hyperparameters *learning rate* and *number of iteration*. The author of the paper has not explored this methodology, therefore we had no information about the value of hyperparameters *learning rate* and *number of iteration*, therefore we ran a simulation study to determine the hyperparameters that delivered values of coefficients very similar to that of the models used by the author

The paper uses linear function in estimating the coefficients of alpha, beta and gamma in the HNIP estimator. The linear model is realized using Ordinary Least Squares (OLS) method. The estimator is replicated by replacing the OLS based linear function with a bayesian regression function. Bayesian linear regression is used because it is more flexible to further model development and can directly model posteriors of derived/calculated quantities. “Bolstad” package provides a bayes.lm function which has been used to complete the replication. Upon analysis, we can conclude that the replicated estimator produced coefficients that are similiar to the actual paper.

The paper uses Ordinary Differential Equations for calculating the supply functions, . For this package ‘odesolve’ has been used in the base paper. Package ‘odesolve’ has been removed from the CRAN repository. The more recent package ‘deSolve’ completely supersedes odesolve and we have installed the same.

## Data

The dataset used by the paper (Epple, Gordon, and Sieg [2010](#ref-epple2010new)) comes from Allegheny County Web site (Pennsylvania state) maintained by the Office of Property assessments, which is based on the appraisals conducted by Sabre Systems and uses land value appraisals as well as property appraisals. Using geocoding, property assignment to travel zones and subsetting only for functioning residential properties, the count came down to 358,677 properties. Of these properties,the authors used a subsample of housing units that were built after 1995 for the estimation procedure which was 6362 houses. The data captures some important metrics for the houses such as the price of land, value per unit land, plot area, travel time and its geo-location (latitude and longitude). We will be using the same data for our replication in this paper. The descriptive statistics of the dataset with 6362 residential properties is shown in Table 1.

#>   
#> Table 1 - Descriptive statistics of Residential data  
#> ===================================================================  
#> Statistic Mean Median St. Dev. Min Max   
#> -------------------------------------------------------------------  
#> Value per unit of land, v 21.44 14.29 26.91 0.15 366.62   
#> Price of land, p 3.32 2.28 3.86 0.05 41.75   
#> Lot area (sq. ft.) 26,756.10 15,507 52,196.96 540 1,207,483  
#> Travel time (minutes) 29.12 30 9.47 1 59   
#> -------------------------------------------------------------------

# Results

For our replication study, we have the results for the following variants introduced in the original paper:  
1. Excluded the top 1 and bottom 1 percentile records from the residential data based on value of unit per land. This is based on the claims by the author that the results were robust to the presence of extreme values.  
2. Added two models to the OLS based estimates- GLM log-linear model and a log-linear model based on gradient descent loss function.  
3. Replicated the supply and production function estimates for generalized log-linear model along with the original models.  
4. Replicated the plots of supply function and production function with 95% CI bands for the generalized log-linear model  
5. Replicated the instrumental variable estimator model(suggested by Hausman, Newey, Ichimura, and Powell (Journal of Econometrics, 1991) estimates based on least squares using Bayesian regression

### Regression estimates and plots

The original paper estimates the r(v) functions using OLS for log-linear, linear, quadratic and cubic models. We obtained similar results using gaussian log-linear model and gradient descent log linear model in addition to the four models. For both of these two models, they fit the main features of the residential data substantially well and their performance is similar to the earlier four models. All the p-values were calculated using heteroskedasticity-robust standard errors and they were significant at 1% level.

#>   
#> Table 2 - Estimates of Equilibrium locus  
#> =============================================================================  
#> OLS and GLM estimates   
#> ----------------------------------------------------------------  
#> Log-Linear Linear Quadratic Cubic Generalized-Log-Linear  
#> -----------------------------------------------------------------------------  
#> logv 0.919\*\*\* 0.919\*\*\*   
#> (0.005) (0.005)   
#>   
#> v 0.153\*\*\* 0.163\*\*\* 0.172\*\*\*   
#> (0.001) (0.001) (0.002)   
#>   
#> v2 -0.0001\*\*\* -0.001\*\*\*   
#> (0.00002) (0.0001)   
#>   
#> v3 0.00000\*\*\*   
#> (0.00000)   
#>   
#> Constant -1.632\*\*\* -1.632\*\*\*   
#> (0.014) (0.014)   
#>   
#> -----------------------------------------------------------------------------  
#> Observations 6,234 6,234 6,234 6,234 6,234   
#> =============================================================================  
#> Note: \*p<0.1; \*\*p<0.05; \*\*\*p<0.01  
#> Gradient\_descent.Log.linear  
#> Constant -1.631195  
#> log(v) 0.918491

As observed in Table 2, while the base paper had slope to be as 0.909 and the intercept coefficient as -1.605 for the log-linear model, we obtained similar results with (0.919,-1.632) and (0.918,-1.631) as (slope, intercept) for our GLM model and gradient descent models respectively.

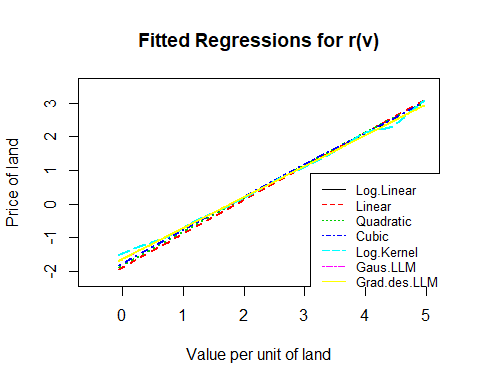


Figure 1: Plot of fitted models

For effective comparison of all the six models used, we have also enclosed a plot as seen in Figure 1. We find all the models to fit the data very well. We were able to establish the monotonicity condition of to be satisfied for the two replication models as well under all the polynomial estimation cases for the range of values of v observed in the data.

### Supply and production function plots

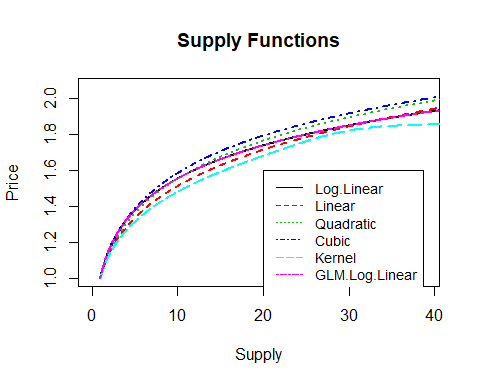


Figure 2: Supply functions by model

As seen in Figure ??, we find that the supply functions are relatively similar for all the original models and we were able to replicate similar results for the GLM log-linear model.

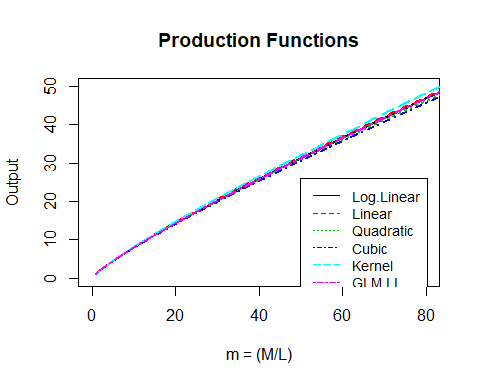


Figure 3: Production functions by model

Similarly,as seen in Figure ??, we find that the production functions are similar for all the original models and we were able to replicate similar results for the GLM log-linear model.

### Replication of supply and production functions with 95% confidence band for GLM Log-linear model

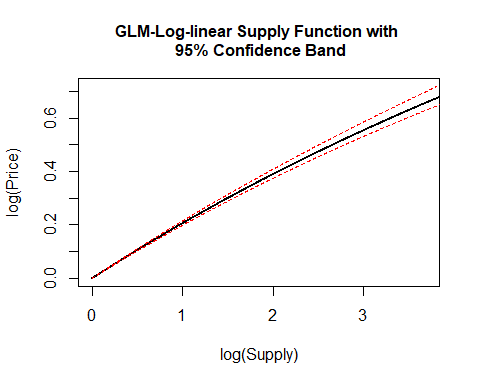


Figure 4: Generalized log-linear supply function with 95 % confidence band

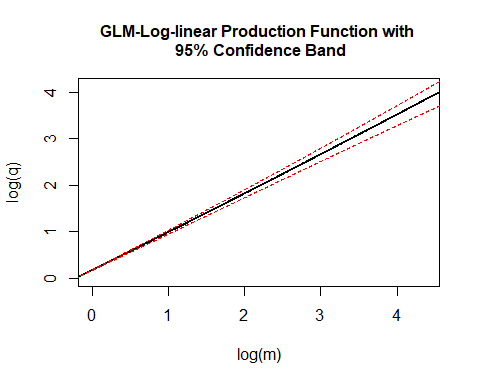


Figure 5: Generalized log-linear supply function with 95 % confidence band

We were also able to replicate the supply and production functions with a 95% confidence interval band for GLM log-linear model as seen in Figures @(fig:glm-supply-func-confidence-band) and @(fig:glm-production-func-confidence-band) and the plots are similar to the plots produced in the original paper.

### Replication of non-linear regressor estimation using HNIP

#> [1] "b = 50"  
#> [1] "b = 100"  
#> [1] "b = 150"  
#> [1] "b = 200"  
#>   
#> Table 3 - HNIP estimates for third order Polynomial  
#> ======================  
#> Cubic mean Cubic SD  
#> ----------------------  
#> v 0.183760 0.014694  
#> v2 -0.000728 0.000286  
#> v3 0.000006 0.000003  
#> ----------------------

The r(v) function replicated using bayesian regression for third order polynomial is similar to the one estimated in the original paper using OL based Linear Regression model. The original paper produced a mean of 0.1732, –0.0005 and 0.000004 for V, V^2 and V^3 coeffiecients respectively and the replicated bayesian model produced similar means of 0.1571414, 0.1974321, 0.1845944, 0.1937378, 0.1789349, 0.1853479, 0.1632442, 0.1926945, 0.1777135, 0.1748193, 0.1832344, 0.1784545, 0.1736887, 0.1556265, 0.1938892, 0.198636, 0.1791989, 0.171401, 0.1911445, 0.1756891, 0.1785683, 0.1881467, 0.1611236, 0.1800487, 0.1541588, 0.1790531, 0.175331, 0.1986219, 0.1711917, 0.1537975, 0.1826019, 0.1837901, 0.1789733, 0.1626637, 0.1562212, 0.1760184, 0.1928155, 0.1951982, 0.1850273, 0.1920634, 0.1903951, 0.1728004, 0.1864623, 0.1975428, 0.1597642, 0.165484, 0.1870756, 0.2456699, 0.1861133, 0.1832708, 0.1891613, 0.1900862, 0.1908093, 0.1793824, 0.1881452, 0.1905851, 0.1627828, 0.1609597, 0.1891364, 0.1863665, 0.1725811, 0.1783464, 0.1833543, 0.1831838, 0.1783773, 0.1805274, 0.1837443, 0.1692425, 0.1881148, 0.1686301, 0.1864997, 0.1751258, 0.1856395, 0.1858922, 0.1824825, 0.2060057, 0.1618497, 0.1823593, 0.1753995, 0.1794314, 0.1975254, 0.1882884, 0.173956, 0.1879706, 0.1878013, 0.1860872, 0.2011392, 0.1675923, 0.1889126, 0.1795144, 0.1850032, 0.1867006, 0.1948219, 0.1928322, 0.1895926, 0.2039319, 0.18199, 0.1753207, 0.1763776, 0.1886995, 0.1641502, 0.1837799, 0.188356, 0.1886059, 0.1835931, 0.1705427, 0.1898898, 0.195776, 0.1663058, 0.2321959, 0.166244, 0.1767671, 0.1776145, 0.1874019, 0.1842622, 0.1519577, 0.1860024, 0.1884098, 0.1928026, 0.1915209, 0.1653491, 0.1940417, 0.1582433, 0.1913054, 0.1899646, 0.172679, 0.1490564, 0.1900811, 0.1879824, 0.2118884, 0.2575236, 0.1931339, 0.1852599, 0.1860116, 0.1857511, 0.2033792, 0.1719425, 0.175734, 0.1926851, 0.1728064, 0.1785678, 0.1920377, 0.1849353, 0.1661418, 0.1858219, 0.1879296, 0.184646, 0.1705703, 0.1569488, 0.1913302, 0.1868216, 0.1855864, 0.1742829, 0.1826864, 0.1952479, 0.1888468, 0.1942446, 0.1939265, 0.1953612, 0.1811091, 0.1844197, 0.1763204, 0.1482183, 0.1836174, 0.1631999, 0.1848866, 0.1935156, 0.1815208, 0.1920632, 0.1729343, 0.1880518, 0.1811176, 0.1926168, 0.179931, 0.1857279, 0.2176515, 0.1870213, 0.1861597, 0.1954166, 0.1915845, 0.1558351, 0.1942403, 0.1903867, 0.2309615, 0.1999301, 0.1867872, 0.2053885, 0.1857552, 0.1878995, 0.1894473, 0.1773877, 0.1881473, 0.1970659, 0.2042356, 0.1663358, 0.2019745, 0.1835182, 0.1866515, 0.1795865, 0.1815008,-3.885057510^{-4}, -5.666869210^{-4}, -5.85124610^{-4}, -5.015084610^{-4}, -9.423754410^{-4}, -6.834204810^{-4}, -4.116030410^{-4}, -0.0011163, -5.20449310^{-4}, -0.0011498, -0.0011354, -8.033141410^{-4}, -8.692093210^{-4}, -5.313890210^{-4}, -5.194181210^{-4}, -0.0010543, -7.699887610^{-4}, -5.119981210^{-4}, -9.195143810^{-4}, -9.051246110^{-4}, -0.0011796, -0.001058, -2.894864810^{-4}, -7.604235210^{-4}, -5.136924510^{-4}, -0.0013175, -0.0012545, -4.605818810^{-4}, -6.018419710^{-4}, -4.44436910^{-4}, -6.270425210^{-4}, -7.536286510^{-4}, -8.438658310^{-4}, -7.648175210^{-4}, 4.935516510^{-5}, -0.0010268, 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8.111411410^{-6}, 4.806940810^{-6}, 5.8755110^{-6}, 4.310942710^{-6}, 3.546705910^{-6}, 6.763407710^{-6}, 3.429086510^{-6}, 4.618586410^{-6}, 9.060144910^{-6}, 3.386463110^{-6}, 1.348567810^{-6}, 5.123017410^{-6}, 5.6028210^{-6}, 2.31458110^{-6}, 6.949041910^{-6}, 4.591983610^{-6}, 4.076008910^{-6}, 8.502001810^{-6}, 6.549514110^{-6}, 7.025655610^{-6}, 7.068410510^{-6}, 3.172504310^{-6}, 4.602322310^{-6}, 3.173040310^{-6}, 8.667210910^{-7}, 8.510221110^{-6}, 8.1112110^{-6}, 2.311679410^{-6}, 6.537782610^{-6} as seen in Table 3.

# Conclusion

We have discussed in the paper (Epple, Gordon, and Sieg [2010](#ref-epple2010new)) about how to estimate the production function for housing. In order to do so, we have worked on calculating the estimation functions and supply functions. We encountered a bit of blockage in calculating the ordinary differential equations since the original paper by (Epple, Gordon, and Sieg [2010](#ref-epple2010new)) calculated it using the now-obsolete ‘odesolve’ package. We were successful in replacing its dependencies with the ‘deSolve’ package. Since price and quantities for house are rarely observed individually, we treated these two metrics as latent variables. Thus, we were able to calculate the production function without resorting to strong functional form assumptions. Of the three main functions: estimation, supply and production, we have replicated the first two functions with different linear model and loss functions. Compared to the four models used in (Epple, Gordon, and Sieg [2010](#ref-epple2010new)) for estimating the , our Gaussian Generalized Log Linear Model and Gradient Descent Log Linear Model had similar performance. The result is illustrated in Table 1. The main insight behind the approach is that the observed variation in land prices and housing values per unit of land is sufficient to identify the housing supply function per unit of land. For estimating the supplyfunctions, we have replicated the results using Gaussian Generalized Log Linear Model.Given the supply function per unit of land it is straightforward to recover the underlying production function.The production functions for housing plays an important role in conducting applied general equilibrium policy analysis. Many urban policies—such as school voucher programs, property tax reforms, urban development policies are likely to affect the demand for housing and residential sorting patterns.

# References

1.@epple2010new

Epple, Dennis, Brett Gordon, and Holger Sieg. 2010. “A New Approach to Estimating the Production Function for Housing.” *American Economic Review* 100 (3): 905–24.