Demand for Total Knee Replacements in the United States:
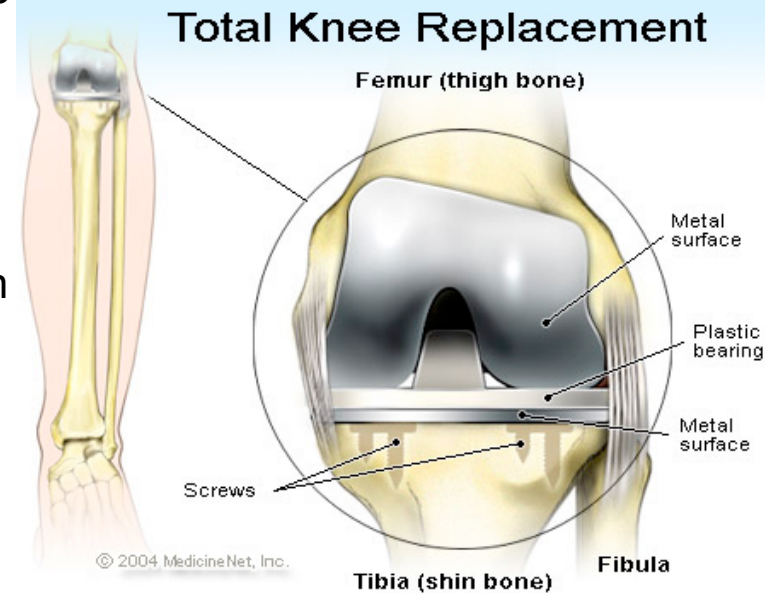# A Preliminary Investigation

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06 December 2011

Introduction

- Currently there are over 600,000 total knee replacements performed in the United States each year.

  - Total Knee Arthroplasty (TKA) is a surgical procedure performed by an orthopedic surgeon which involves the removal of diseased bone in the patellofemoral joint and replacing with metal or synthetic material to reconstruct the joint.

  - The procedure is performed primarily to alleviate pain and restore function in patients with moderate to severe joint degeneration.

  - TKA is one of most common orthopedic procedures and between 2005 and 2030, the demand for TKR is expected to grow by 601% . [1]

- The purpose of this preliminary study is to identify the variables which explain the demand for this procedure.

Total Knee Replacement
Femur (thigh bone)
Metal surface
Plastic bearing
Metal surface
Screws
Tibia (shin bone)
Fibula
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Previous Literature

- Geographic Variations in the Rates of Elective Total Hip and Knee Arthroplasties among Medicare Beneficiaries in the United States [2]
    - Investigation performed at the Cornell Arthritis and Musculoskeletal Disease Center, Cornell University Medical Center and The Hospital for Special Surgery, New York City
    - This article analyzes the variations in the rates of elective total knee replacements in the US to determine whether the rates correlated with the number of surgeons in 1988.

- BMC Musculoskeletal Disorders (Research article) [3]
    - A comprehensive joint replacement program for total knee arthroplasty: a descriptive study

- Using the HCUP Nationwide Inpatient Sample to Estimate Trends (Updated for 1988-2004) Report # 2006-05 [4]
    - HCUP uses The Nationwide Inpatient Sample(NIS) to identify, track, and analyze national trends in health care, access, charges, quality, and outcomes. It is sponsored by The Agency For Healthcare Policy And Research.

- EULAR Recommendations 2003: an evidence based approach to the management of knee osteoarthritis: Report of a Task Force of the Standing Committee for International Clinical Studies Including Therapeutic Trials (ESCISIT) [5]
    - Osteoarthritis results in disabling knee symptoms in an estimated 10% of people older than 55 years, a quarter of whom are severely disabled.

Hypotheses

- H_1 = The demand for TKA is explained by increasing US population 50 years and older.

- H_2 = The demand for TKA is explained by increasing incidence of obesity.

- H_3 = The demand for TKA is explained by increasing density of orthopedic surgeons relative to US population.

Methodology

- Data from numerous medical journals, academic papers, and public databases were converted into variables and synthesized using WinORS
  - Dummy variable for "War Effect" was created to account for years the US was involved in a declared war

- Ordinary Least Squares (OLS) regression was used to refine the model across the independent variables against the dependent variable to determine the best model

- Testing for Multicollinearity, Serial/auto Correlation, Homoscedasticity, and Normality

- Demand equation was formed using regression parameters without an intercept (insignificant variable)

Data

- Time series data from 1991 – 2008

Dependant Variable	Data Source
Total Knee Arthroplasty (TKA) per year (000)	Orthopedics Data Compendium: Use, Cost, and Market Structure for Total Joint Replacement, Integrated Healthcare Association, August 2006. (http://www.iha.org/pdfs_documents/medical_device/07_OrthopedicsDataCompendium.pdf) and Academy of Orthopedic Surgeons (www.aaos.org)

Data

Independent Variables	Data Source
US Population	U.S. Census Bureau (http://www.census.gov/popest/archives/)
US Population 50 years and older	U.S. Census Bureau (http://www.census.gov/popest/archives/)
Population that has any kind of health care coverage	Centers for Disease Control and Prevention (http://apps.nccd.cdc.gov/BRFSS/index.asp)
Medicare Enrollment	Centers for Medicare & Medicaid Services (http://www.cms.gov/MedicareEnRpts/Downloads/HISMI2010.pdf)
Incidence of US Obesity over 20 years of age (percent)	Journal of the Royal Society of Medicine (http://www.ncbi.nlm.nih.gov/pmc/articles/PMC1457748/)
US Population over 20 years with Diagnosed Diabetes (000)	Centers for Disease Control and Prevention (http://www.cdc.gov/nchs/fastats/overwt.htm)
Average US Life Expectancy	U.S. Census Bureau (http://www.census.gov/popest/archives/)
Density of Orthopedic Surgeons per 100,000 in US	Academy of Orthopedic Surgeons (www.aaos.org)

Data

Independent Variables	Data Source
Medicare Physician Payments for Total Knee Replacement ($M)	Orthopedic Network News (http://www.orthopedicnetworknews.com/newsletterarchives.html)
Total US Personal Healthcare Expenditures ($B)	Centers for Medicare & Medicaid Services (https://www.cms.gov/MedicareMedicaidStatSupp/09_2010.asp) Table 1.2
Total Medicare Personal Healthcare Expenditures ($B)	Centers for Medicare & Medicaid Services (https://www.cms.gov/MedicareMedicaidStatSupp/09_2010.asp) Table 1.2
Knee Implant US Sales ($M)	Orthopedic Network News (http://www.orthopedicnetworknews.com/newsletterarchives.html)
Average Knee Implant Cost ($)	Orthopedic Network News (http://www.orthopedicnetworknews.com/newsletterarchives.html)
Ave Sales/Cost	Calculated
US GDP ($)	Bureau of Labor Statistics (http://www.bls.gov/)
Consumer Price Index	Bureau of Labor Statistics (http://www.bls.gov/)
Annual Average Unemployment Rate, civilians 16 years and over (percent)	Bureau of Labor Statistics (http://www.bls.gov/)
Dummy variable: War Effect	Wikipedia (http://en.wikipedia.org/wiki/Declaration_of_war_by_the_United_States

Significant Variables

- Dependent Variable = Total Knee Arthroplasty (TKA)

Independent Variables	Expected Sign	Parameter Estimate	Standard Error	t for Ho: Est = 0	P-Value (0.05)	VIF
Intercept						n/a
Incidence of US Obesity over 20 years of age (percent)	+	14.068	2.538	5.544	0.00013	9.174
Medicare Physician Payments for Total Knee Replacement ($M)	+	-0.059	0.012	-5.132	0.00023	1.000
Average Knee Implant Cost ($)	-	0.030	0.007	4.481	0.00060	4.827

Insignificant Variables

Independent Variables	Expected Sign	Type
US Population	+	Exo
Average US Life Expectancy by Year	+	Exo
Dummy: War Effect	+	Exo
US Population Aged 50 and over	+	Exo
Density of Orthopedic Surgeons per 100000 in US	+	Endo
Number of US Population over 20 years with Diagnosed Diabetes	+	Exo
Population that has any kind of health care coverage	+	Endo

Independent Variables	Expected Sign	Type
US GDP	+	Exo
Total US Personal Healthcare Expenditures	+	Endo
Total Medicare Personal Healthcare Expenditures	+	Endo
Medicare Enrollment	+	Endo
Knee Implant US Sales	+	Endo
Consumer Price Index	+	Exo
Annual Average Unemployment Rate, civilians 16 years and over	-	Exo

Estimated Model

- The demand function is expressed as:

  Q = +14.068 (Obesity) -0.059(Medicare Payment) +0.030(Implant Cost) + ε

  - Where ε = residual error
  - Note: no intercept

- F Statistic: 1278.995
  - P Value: 0.00001
- R-Squared: 99.611 %
- Adjusted R-Squared: 99.559

Predictive Ability (OLS)
Dependent Variable: Total Knee Arthroplasty (TKA) per Year (000)
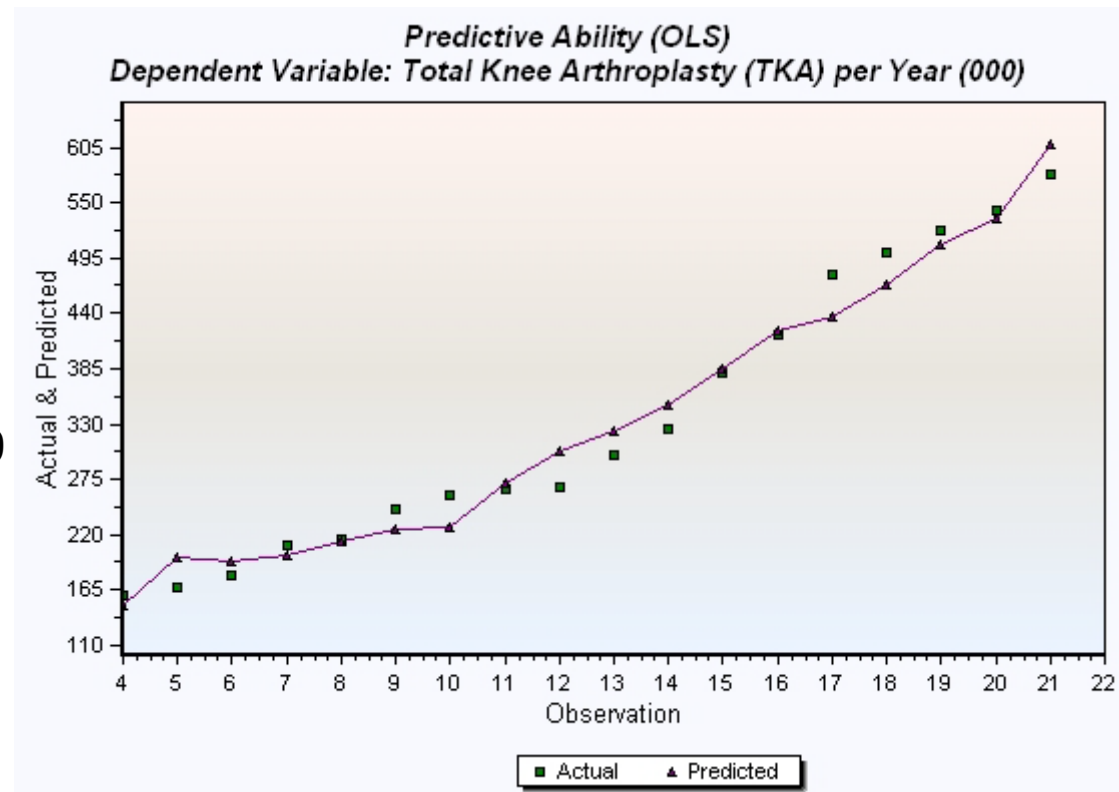
Results: Multicolinearity

- VIF: Variance Inflation Factor
    - Average VIF: 5.000

Variable	VIF
Incidence of US Obesity over 20 years of age (percent)	9.174
Medicare Physician Payments for Total Knee Replacement ($M)	1.000
Average Knee Implant Cost ($)	4.827

Results: Serial / Auto Correlation

- Time Series Data – therefore check for serial / auto correlation

- Durbin Watson

Auto Correlation	
Rho	0.395
Durbin	1.095
Durbin H	n/c
D Lower Limit	1.046
D Upper Limit	1.535
Ho: Rho = 0	
Rho: Pos & Neg	Inconclusive
Rho: Positive	Do Not Reject
Rho: Negative	Inconclusive

- Inconclusive evidence for auto correlation

- Rho indicates some level auto correlation between the variables
  - Not very close to zero but not too close to 1.0 either

Results: Constant Variance

- White's Test for Homoscedasticity: 6.998
  - P Value: 0.63729

Constant Variance Test (OLS)
Dependent Variable: Total Knee Arthroplasty (TKA) per Year (000)
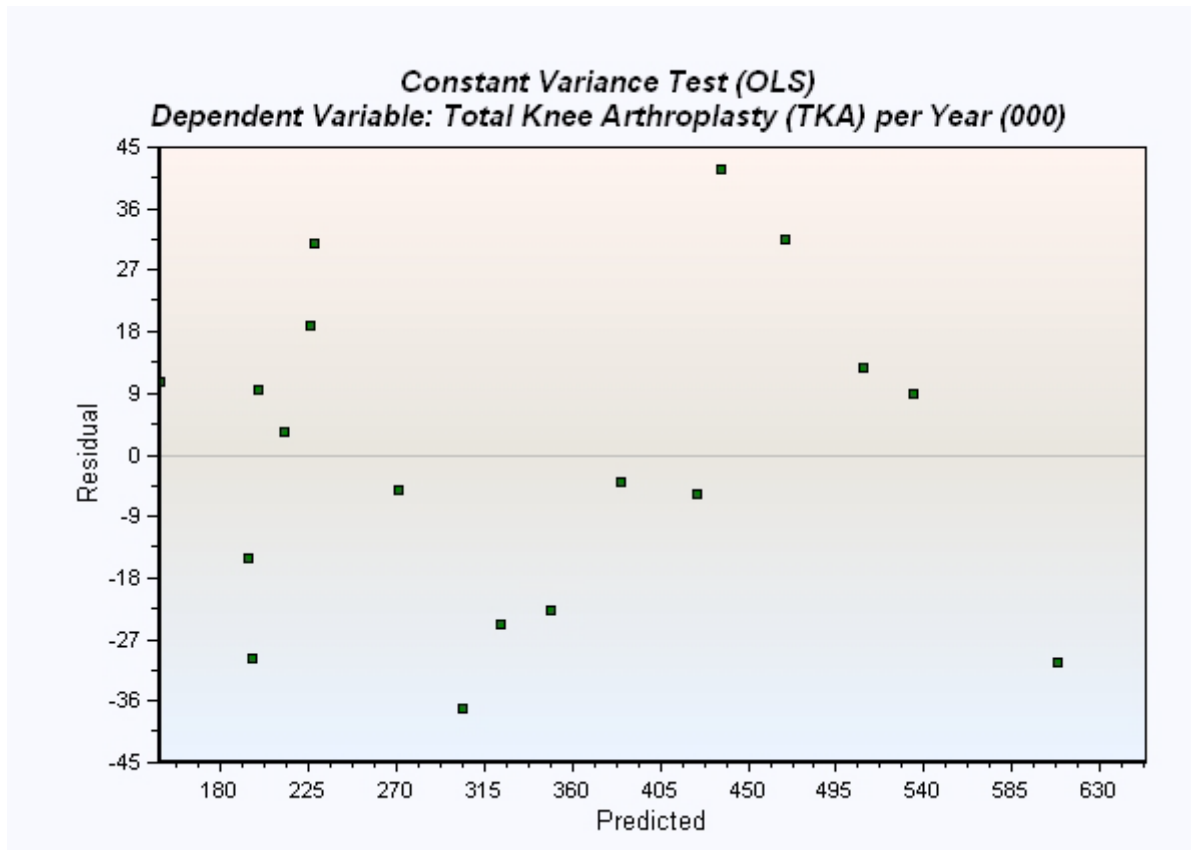
Results: Normal Distribution of Error Terms

- Correlation of Normality: 0.9881
- Approximate Critical Value: 0.9510

Normal Probability Chart (OLS)
Dependent Variable: Total Knee Arthroplasty (TKA) per Year (000)
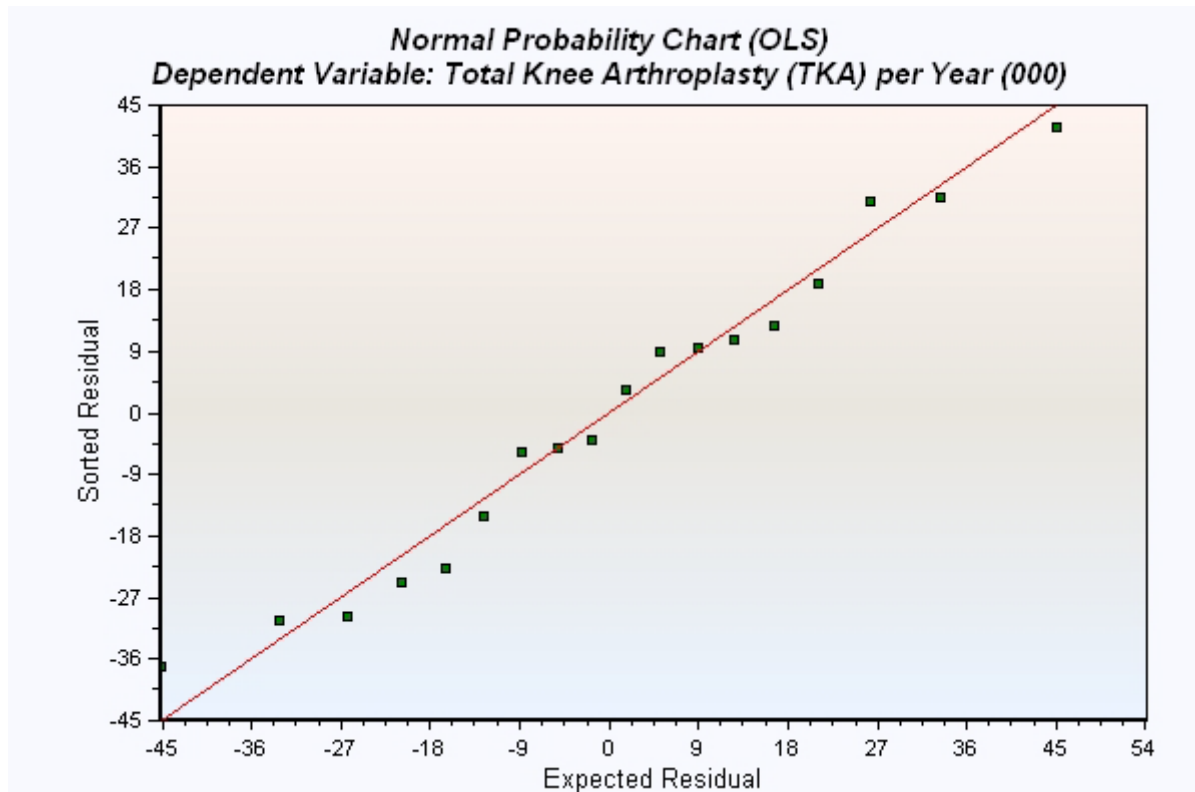
Elasticity

- How will demand for Total Knee Arthroplasty (TKA) change given changes in Obesity, Medicare payments to physicians or cost of knee implants?

| Independent Variable	Average Elasticity	Elastic?
Incidence of US Obesity over 20 years of age (percent)	0.90054	~Unit Elastic
Medicare Physician Payments for Total Knee Replacement ($M)	-0.38475	Inelastic
Average Knee Implant Cost ($)	0.49159	Inelastic

Hypotheses Revisted

- H_1 = The demand for TKA is explained by increasing US population 50 years and older.
  - Reject; not a significant variable

- H_2 = The demand for TKA is explained by increasing incidence of obesity.
  - Preliminary accept (due to low degrees of freedom)

- H_3 = The demand for TKA is explained by increasing density of orthopedic surgeons relative to US population.
  - Reject; not a significant variable
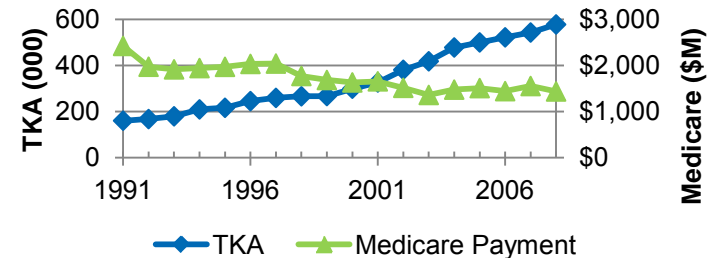
Policy Implications

- As the "Baby Boomer" population ages in tandem with longer US life expectancy and rising incidence of US obesity, the number of TKA procedures continue to climb

- Medicare Physician reimbursement has decreased in recent years despite the increase in demand for TKA

- Recent socio-political pressure to cut Medicare costs as part of an overall plan to rein in government spending has set the stage for a continued trend of decreased Medicare physician payments

- Orthopedic implant costs continue to trend upwards. Combined with decreased physician reimbursement, profit margins for surgeons and hospitals continue to erode while margins for the implant manufacturers remain robust
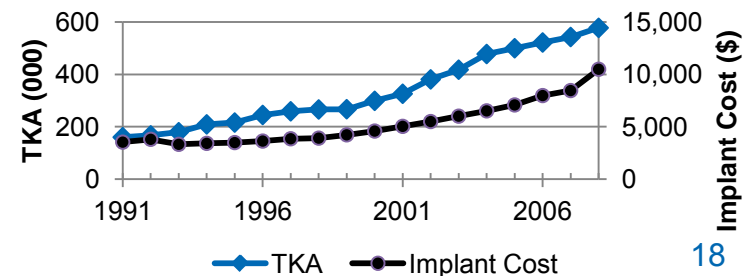
TKA and Obesity
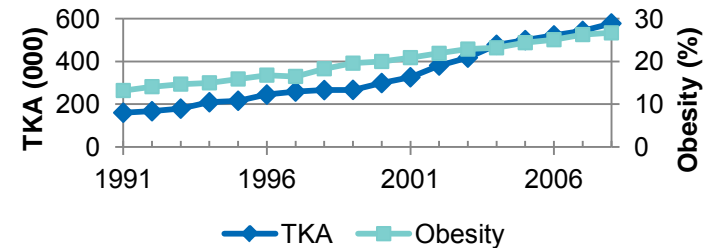
TKA and Medicare

TKA and Implant Cost

Policy Implications

- The effect of obesity on the Medicare system (TKA, Diabetes, Heart Disease, ect.) compounds the current Medicare spending policy

- Resources that could be utilized for prevention and wellness programs are used to treat preventable chronic diseases

- Demand model shows:
  - Policies that redirect Medicare resources toward the prevention of obesity (and other chronic conditions) may decrease the demand for reactive procedures (TKA) and decrease overall Medicare expenditures
  - Clear exploitation by manufacturers of the inelastic demand of rising implant costs. Future Medicare policy may address this in the form of tax implications to offset expenditures
  - Hospitals/Surgeons may opt for inexpensive, lower quality implants to reduce the effect of reduced reimbursement on their margins resulting in increasing incidences of TKA revision = increased Medicare costs!!!

References

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[2]   Peterson, M. G. E., J. P. Hollenberg, T. P. Szatrowski, N.A. Johanson, C. A. Mancuso, and M. E. Charlson. *Geographic Variations in the Rates of Elective Total Hip and Knee Arthroplasties among Medicare Beneficiaries in the United States.* The Journal of Bone & Joint Surgery. 1992; 74:1530-1539. This article is available from: http://www.jbjs.org/article.aspx?Volume=74&page=1530

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[4]   U.S. Department of Health and Human Services, Agency for Healthcare Research and Quality. *Using the HCUP Nationwide Inpatient Sample to Estimate Trends (Updated for 1988-2004), Report # 2006-05.* This is from: http://www.hcup-us.ahrq.gov/reports/methods/2006_05_NISTrendsReport_1988-2004.pdf

[5]   Jordan KM, Arden NK, Doherty M, Bannwarth B, Bijlsma JW, Dieppe P, Gunther K, Hauselmann H, Herrero-Beaumont G, Kaklamanis P, Lohmander S, Leeb B, Lequesne M, Mazieres B, Martin-Mola E, Pavelka K, Pendleton A, Punzi L, Serni U, Swoboda B, Verbruggen G, Zimmerman-Gorska I, Dougados M; Standing Committee for International Clinical Studies Including Therapeutic Trials ESCISIT. EULAR Recommendations 2003: an evidence based approach to the management of knee osteoarthritis: Report of a Task Force of the Standing Committee for International Clinical Studies Including Therapeutic Trials (ESCISIT). Annuals of the Rheumatic Diseases. 2003 Dec;62(12):1145-55. This is from: http://www.ncbi.nlm.nih.gov/pubmed/14644851

Questions?

Data

Year	Total Knee Arthroplasty (TKA) per Year (000)	US Population	Average US Life Expectancy by Year	Density of Orthopedic Surgeons per 100000 in US	Dummy: War Effect	US Population Aged 50 and over	Incidence of US Obesity over 20 years of age (percent)	Number (in Thousands) of US Population over 20 years with Diagnosed Diabetes	Medicare Physician Payments for Total Knee Replacement ($M)	US GDP	Total US Personal Healthcare Expenditures ($B)	Total Medicare Personal Healthcare Expenditures ($B)	Medicare Enrollment	Knee Implant US Sales ($M)	Consumer Price Index	Annual Average Unemployment Rate, civilians 16 years and over (percent)	Average Knee Implant Cost ($)	Ave Sales/Cost
	D						I	I									I	
1991	160	252153000	75.5	5.3	1	64430000	13.2	6928	$2,424	5992.1	677.4	117.3	34870240	$545.00	136.2	6.8	3528.29	0.154
1992	167	255030000	75.8	5.3	0	65271000	14.1	7451	$1,972	6342.3	733.4	132.4	35579149	696	140.3	7.5	3798.29	0.183
1993	179	257783000	75.54	5.4	0	66455000	14.7	7631	$1,915	6667.4	781	146.2	36305903	$847.00	144.5	6.9	3319.67	0.255
1994	209	260327000	75.7	5.6	0	67414000	15	8060	$1,943	7085.2	823	163.4	36935366	$876.00	148.2	6.1	3410.67	0.257
1995	216	262803000	75.79	5.6	0	68394000	15.9	8008	$1,970	7414.7	872.7	179.9	37535024	$965.00	152.4	5.6	3485.33	0.277
1996	245	265229000	76.12	5.8	0	69237000	16.8	8796	$2,033	7838.5	921.7	193.6	38064129	$980.60	156.9	5.4	3629.67	0.27
1997	259	267784000	76.51	5.8	0	71159000	16.5	9406	$2,041	8332.4	974.5	204.2	38444739	$1,045.70	160.5	4.9	3851	0.272
1998	266	270248000	76.71	5.9	0	72775000	18.3	10488	$1,771	8793.5	1028.3	202.4	38824855	$1,065.60	163	4.5	3909.67	0.273
1999	267	272691000	76.73	5.8	0	74374000	19.6	11136	$1,684	9353.5	1088.8	205.7	39140386	$1,113.90	166.6	4.2	4225.67	0.264
2000	299	282162411	76.62	5.8	0	77278081	20	12013	$1,631	9951.5	1164.4	215.9	39619986	$1,219.20	172.2	4	4586.33	0.266
2001	326	284968955	76.58	5.9	1	79082871	20.9	12884	$1,655	10286.2	1264.1	238.8	40025724	$1,352.70	177.1	4.7	5036.75	0.269
2002	381	287625193	76.86	6.1	1	80965445	21.9	13566	$1,514	10642.3	1371.6	256	40488878	$1,540.30	179.9	5.8	5495.5	0.28
2003	418	290107933	77.14	6.1	1	82969752	22.9	14275	$1,359	11142.1	1479	273.8	41086981	1999.95	184	6	6009.5	0.333
2004	478	292805298	77.43	6.2	1	85073291	23.2	15221	$1,475	11867.8	1585	300.2	41693375	$2,459.60	188.9	5.5	6515.25	0.378
2005	500	295516599	77.71	6.2	1	87370028	24.4	16295	$1,508	12638.4	1692.6	326.4	42342234	$2,879.50	195.3	5.1	7082	0.407
2006	522	298379912	77.85	6.1	1	89665093	25.1	17014	$1,442	13398.9	1798.8	381.7	43252055	$3,080.60	201.6	4.6	7977.33	0.386
2007	543	301231207	78	6.7	1	92094323	26.3	17842	$1,553	14061.8	1904.3	407.4	44009689	$3,365.90	207.3	4.6	8456.33	0.398
2008	578	304093966	78.14	7.2	1	94574158	26.7	18958	$1,435	14369.1	1997.2	440.8	45517331	$3,676.30	215.3	5.8	10492.67	0.35

Blue font = interpolated

Regression Tables and Graphics

ANOVA Table

Dep: Total Knee Arthroplasty (TKA) per Year (000)				
Sources	**SSQ**	**MSQ**	**Df**	**F-Value**
Model	2331366.944	777122.315	3	1278.995
Error	9114.056	607.604	15	**P-Value**
C.Total	2340481.000		18	0.00001
Association Test		**MLE Stats**		
Root MSE	24.650	Lambda	====>	n/c
SSQ(Res)	9114.056	LogLiklihood	====>	n/c
Dep.Mean	334.056			
Coef of Var (CV)	7.379%			
Multiple R	99.805%			
R-Squared	99.611%			
Adj R-Squared	99.559%			
Auto Correlation		**Diagnostic Tests**		
Rho	0.395	White's Test for Homoscedasticity	====>	6.998
Durbin	1.095	P-Value for White's	====>	0.63729
Durbin H	n/c			
D Lower Limit	1.046	Average VIF	====>	5.000
D Upper Limit	1.535			
Ho: Rho = 0		**Suggested Transformation**		
Rho: Pos & Neg	Inconclusive			
Rho: Positive	Do Not Reject	**Correlation for Normality**	====>	0.9881
Rho: Negative	Inconclusive	**Approx. Critical Value**	====>	0.9510

Regression Parameters

Variable	Parameter Estimate	Standard Error	t For Ho: Est = 0	P-Value (95%=0.05)	CI Lower 95%	CI Upper 95%
Intercept						
Incidence of US Obesity over 20 years of age (percent)	14.068	2.538	5.544	0.00013	8.688	19.448
Medicare Physician Payments for Total Knee Replacement (mil)	-0.059	0.012	-5.132	0.00023	-0.084	-0.035
Average Knee Implant Cost (USD)	0.030	0.007	4.481	0.00060	0.016	0.045
Dependent:	Total Knee Arthroplasty (TKA) per Year (000)					

Regression Parameters

Variable	CI Lower 85%	CI Upper 85%	Partial Corr	VIF
Intercept				n/a
Incidence of US Obesity over 20 years of age (percent)	10.230	17.906	0.672	9.174
Medicare Physician Payments for Total Knee Replacement (mil)	-0.077	-0.042	-0.637	1.000
Average Knee Implant Cost (USD)	0.020	0.040	0.572	4.827
Dependent:				

Residual Analysis

Obs	Total Knee Arthroplasty (TKA) per Year (000) Actual	Total Knee Arthroplasty (TKA) per Year (000) Predicted	Residual	CLI Lower 95.00%	CLI Upper 95.00%	Std.Resid
***Outlier	160.000	149.212	10.788	115.897	182.526	0.438
Obs 5	167.000	196.757	-29.757	175.328	218.187	-1.207
Obs 6	179.000	194.083	-15.083	177.239	210.926	-0.612
Obs 7	209.000	199.402	9.598	182.399	216.405	0.389
Obs 8	216.000	212.727	3.273	195.920	229.534	0.133
Obs 9	245.000	226.033	18.967	208.707	243.358	0.769
Obs 10	259.000	228.038	30.962	210.912	245.164	1.256
Obs 11	266.000	271.093	-5.093	253.775	288.411	-0.207
Obs 12	267.000	304.086	-37.086	284.522	323.650	-1.505
Obs 13	299.000	323.760	-24.760	305.914	341.606	-1.004
Obs 14	326.000	348.634	-22.634	331.880	365.388	-0.918
Obs 15	381.000	384.918	-3.918	366.551	403.284	-0.159
Obs 16	418.000	423.701	-5.701	403.054	444.348	-0.231
Obs 17	478.000	436.371	41.629	419.461	453.282	1.689
Obs 18	500.000	468.454	31.546	450.633	486.274	1.280
Obs 19	522.000	509.297	12.703	488.546	530.047	0.515
Obs 20	543.000	534.114	8.886	512.071	556.156	0.361
***Outlier	578.000	608.339	-30.339	567.050	649.628	-1.231

Correlation Matrix

	Total Knee Arthroplasty (TKA) per Year (000)	Incidence of US Obesity over 20 years of age (percent)	Medicare Physician Payments for Total Knee Replacement (mil)	Average Knee Implant Cost (USD)
	D	I	I	I
Total Knee Arthroplasty (TKA) per Year (000)	1.000	0.979	-0.840	0.956
Incidence of US Obesity over 20 years of age (percent)	0.979	1.000	-0.898	0.921
Medicare Physician Payments for Total Knee Replacement (mil)	-0.840	-0.898	1.000	-0.745
Average Knee Implant Cost (USD)	0.956	0.921	-0.745	1.000

Rho=0 Matrix

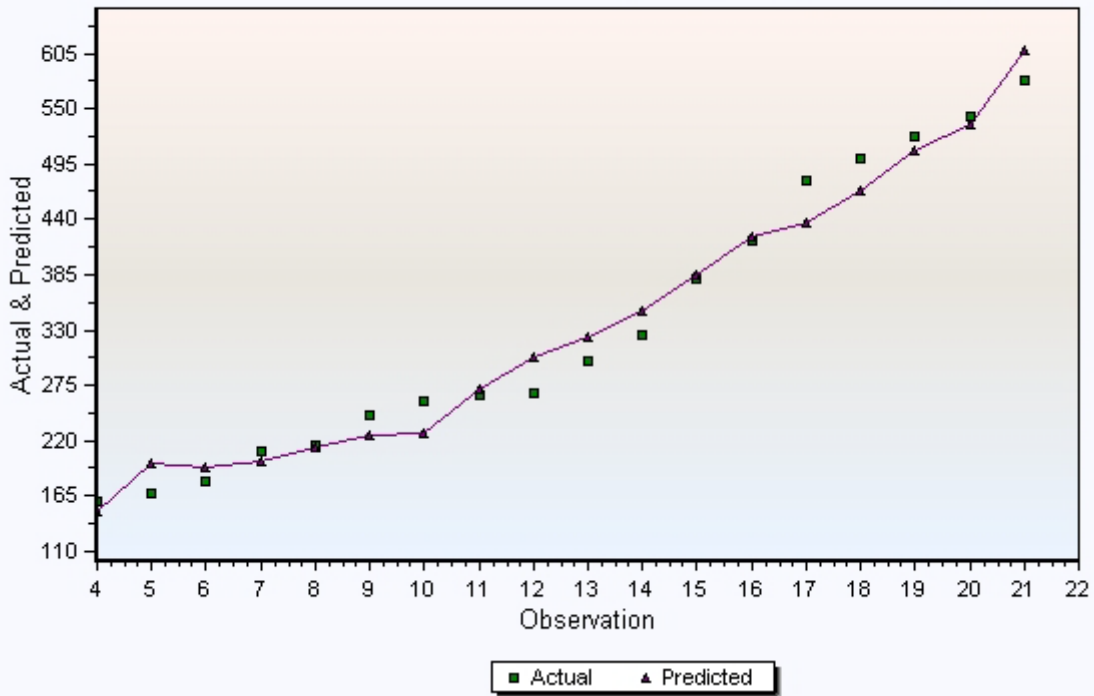|	Total Knee Arthroplasty (TKA) per Year (000)	Incidence of US Obesity over 20 years of age (percent)	Medicare Physician Payments for Total Knee Replacement (mil)	Average Knee Implant Cost (USD)
	D	I	I	I
Total Knee Arthroplasty (TKA) per Year (000)	.	0.00001	0.00006	0.00001
Incidence of US Obesity over 20 years of age (percent)	0.00001	.	0.00001	0.00001
Medicare Physician Payments for Total Knee Replacement (mil)	0.00006	0.00001	.	0.00061
Average Knee Implant Cost (USD)	0.00001	0.00001	0.00061	.

Covariance Matrix

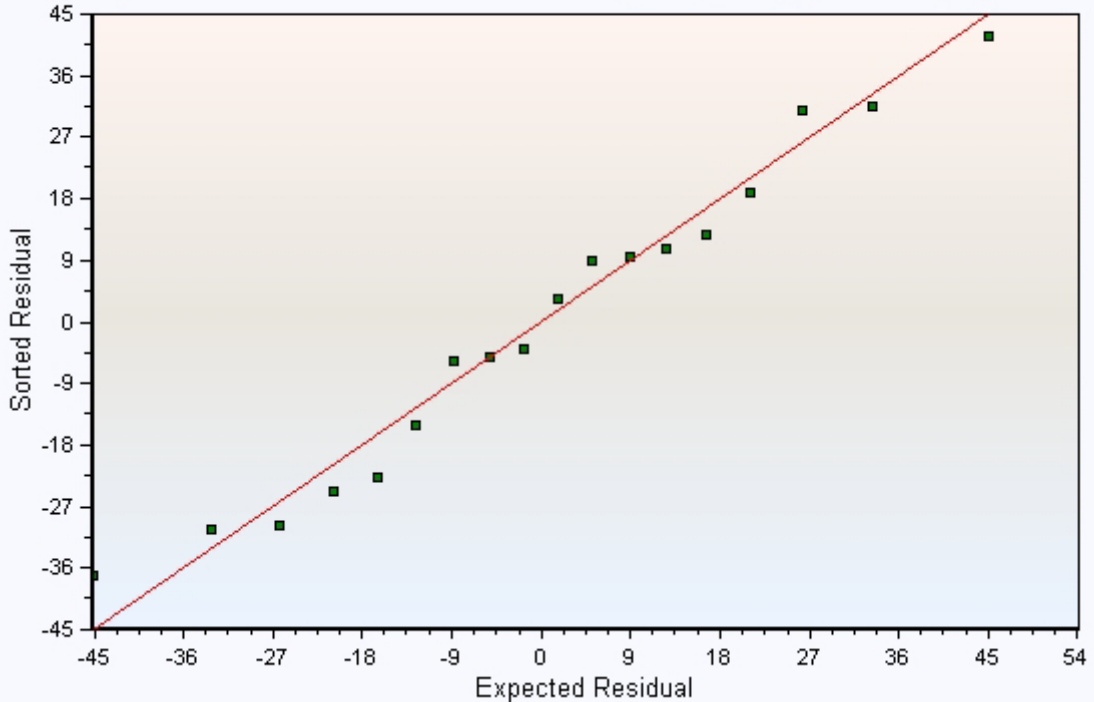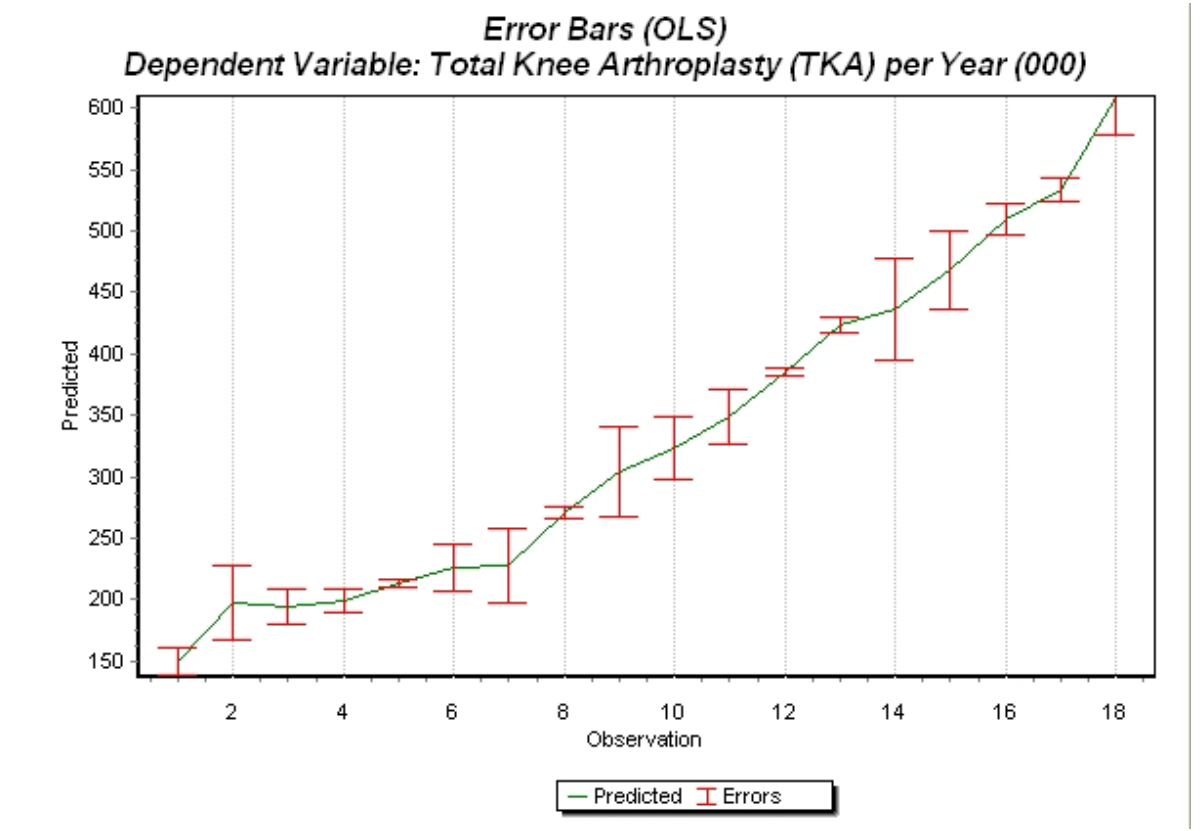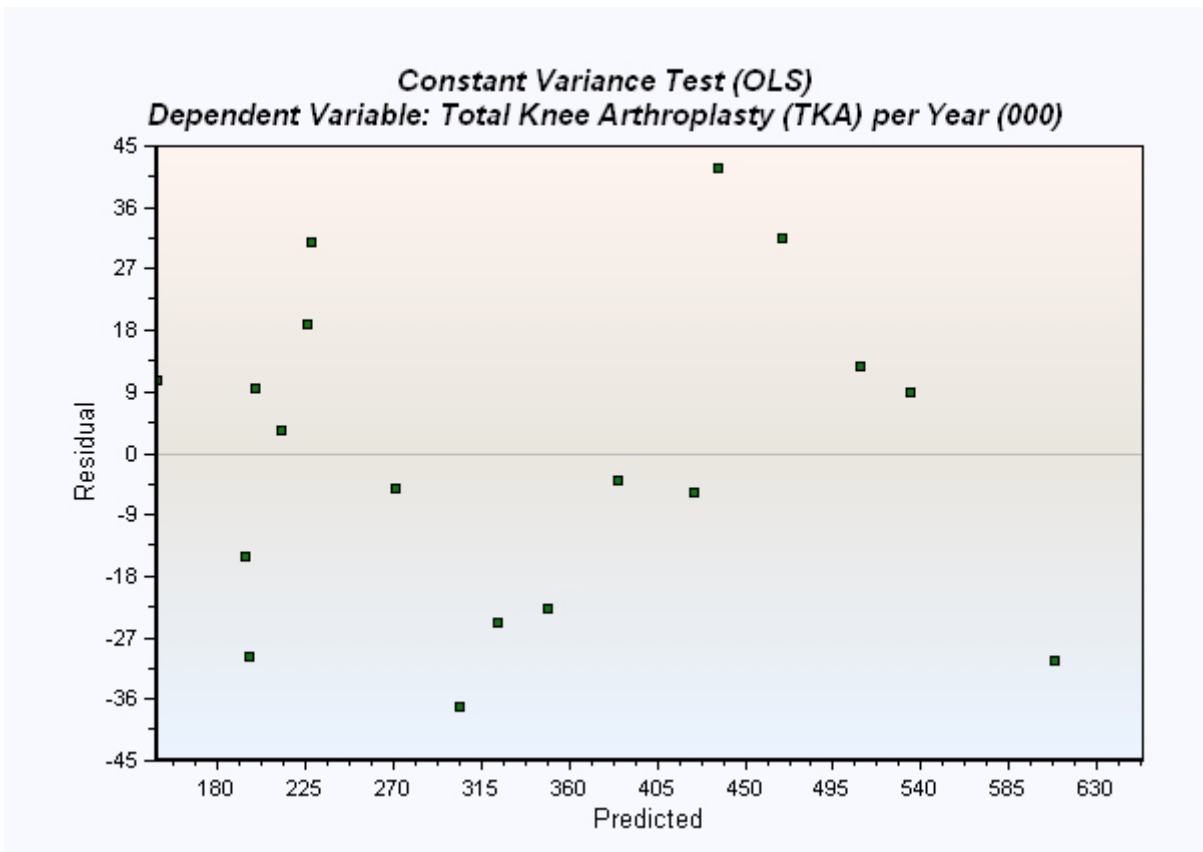|	Total Knee Arthroplasty (TKA) per Year (000)	Incidence of US Obesity over 20 years of age (percent)	Medicare Physician Payments for Total Knee Replacement (mil)
	D	I	I
Total Knee Arthroplasty (TKA) per Year (000)	19517.938	600.938	-33455.193
Incidence of US Obesity over 20 years of age (percent)	600.938	19.317	-1126.274
Medicare Physician Payments for Total Knee Replacement (mil)	-33455.193	-1126.274	81361.742
Average Knee Implant Cost (USD)	278641.521	8447.325	-443393.639

Elasticity

	Incidence of US Obesity over 20 years of age (percent)	Medicare Physician Payments for Total Knee Replacement (mil)	Average Knee Implant Cost (USD)
	I	I	I
Obs 4	1.16061	-0.89538	0.66734
Obs 5	1.18778	-0.69789	0.68829
Obs 6	1.15531	-0.63228	0.56123
Obs 7	1.00967	-0.54944	0.49385
Obs 8	1.03556	-0.53902	0.48831
Obs 9	0.96467	-0.49042	0.44833
Obs 10	0.89623	-0.46573	0.44996
Obs 11	0.96784	-0.39349	0.44480
Obs 12	1.03271	-0.37276	0.47895
Obs 13	0.94101	-0.32239	0.46419
Obs 14	0.90191	-0.30004	0.46756
Obs 15	0.80864	-0.23485	0.43650
Obs 16	0.77071	-0.19215	0.43507
Obs 17	0.68280	-0.18237	0.41248
Obs 18	0.68652	-0.17825	0.42864
Obs 19	0.67645	-0.16326	0.46248
Obs 20	0.68138	-0.16903	0.47129
Obs 21	0.64986	-0.14673	0.54936
Average==>	0.90054	-0.38475	0.49159

Predictive Ability (OLS)
Dependent Variable: Total Knee Arthroplasty (TKA) per Year (000)

Normal Probability Chart (OLS)
Dependent Variable: Total Knee Arthroplasty (TKA) per Year (000)

Constant Variance Test (OLS)
Dependent Variable: Total Knee Arthroplasty (TKA) per Year (000)

Error Bars (OLS)
Dependent Variable: Total Knee Arthroplasty (TKA) per Year (000)

Confidence Intervals (OLS)
Dependent Variable: Total Knee Arthroplasty (TKA) per Year (000)