Energy Economics and Policy
AUEB

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Lecture 3:
Energy Economic
Modelling

Objectives

- How do we analyse demand patterns?

- Important to:

  - Understand factors that influence energy consumption
  - Get information on price and income elasticities
  - Forecast energy demand

- Energy Economic Modelling

  - Econometric modelling (OLS regression)
  - CGE modelling (model economic flows using assumptions on production, demand, trade, taxation, etc.)

Energy Demand

Bloomberg Opinion

Actually, Trade Wars Aren't Good (For Oil, Anyway)

One of the first casualties could be demand for gasoline.

By Liam Denning
March 2, 2018, 7:05 PM GMT+1

Gasoline demand isn't just a function of price and fuel efficiency; employment and wages also have a big impact. Yet that is also cause for concern, as payroll trends have been good and gasoline demand still flattened out.

The data suggest U.S. drivers have become more sensitive to gasoline prices and demand elasticity may now be higher than it once was.

Should a trade war exacerbate inflation, gasoline demand could be an early casualty. This is especially so because the tariffs being contemplated would have a disproportionate effect on the construction and automotive industries, both deeply entwined with fuel demand and big employers.

Demand elasticities a function of many variables:
Example: income, economic cycle, inflation, industry, social segment,…

Energy Demand

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Gasoline Demand in Greece: The Importance of Shifts in the Underlying Energy Demand Trend

DAVID C. BROADSTOCK[1,2] and ELENI PAPATHANASOPOULOU[3,4]

This paper explores the relative importance of factors other than price and income in explaining gasoline demand in Greece between 1978 and 2008. Using a structural time series model (STSM) the long-run elasticities of income and price are 0.45 and −0.32, respectively. Further, it is shown using the estimated underlying energy demand trend (UEDT) that other exogenous factors have been shifting the gasoline demand curve to the right, thus reflecting more energy-intensive lifestyles in Greece. Given the results, it is contended that the kinds of policies that governments can use to manage gasoline demand and move toward sustainable transportation go beyond the usual price mechanism.

Energy Demand

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Elasticities of gasoline demand in Switzerland

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A B S T R A C T

Using cointegration techniques, we investigate the determinants of gasoline demand in Switzerland over the period 1970–2008. We obtain a very weak price elasticity of −0.09 in the short run and −0.34 in the long run. For fuel demand, i.e. gasoline plus diesel, the corresponding price elasticities are −0.08 and −0.27. Our rich dataset allows working with quarterly data and with more explicative variables than usual in this literature. In addition to the traditional price and income variables, we account for variables like vehicle stocks, fuel prices in neighbouring countries, oil shocks and fuel taxes. All of these additional variables are found to be significant determinants of demand.

→ Why elasticity falls when diesel is included?

→ Maybe more specific uses of diesel cars with less alternatives?

Energy Demand

Factors that influence energy demand

- Prices (P), Income (I), energy services (S), education …
- Climate (C), lifestyle (LS), culture, location, …
- Efficiency of technology (ϕ), policy (τ), …

↓

$$E = f(P, I, S, \dots, C, LS, \dots, \phi, \tau)$$

Goals of empirical analysis

- Estimation of the short- and long-run price elasticities

$$\epsilon_D = \frac{\frac{\Delta q}{q}}{\frac{\Delta p}{p}} = \frac{\Delta q}{\Delta p}\frac{p}{q} \quad \text{and} \quad \epsilon_{ij} = \frac{\Delta q_i}{\Delta p_j}\frac{p_j}{q_i}$$

(own price elasticity and cross-price elasticities)

- Estimation of the short- and long-run income elasticities

$$\epsilon_I = \frac{\Delta q}{\Delta I}\frac{I}{q}$$

- Analysis of the impacts of other factors (e.g. education, climate, …)

- Analysis of the ex-post impact of policy instruments (e.g. taxes, subsidies, tariffs, energy standards, …)

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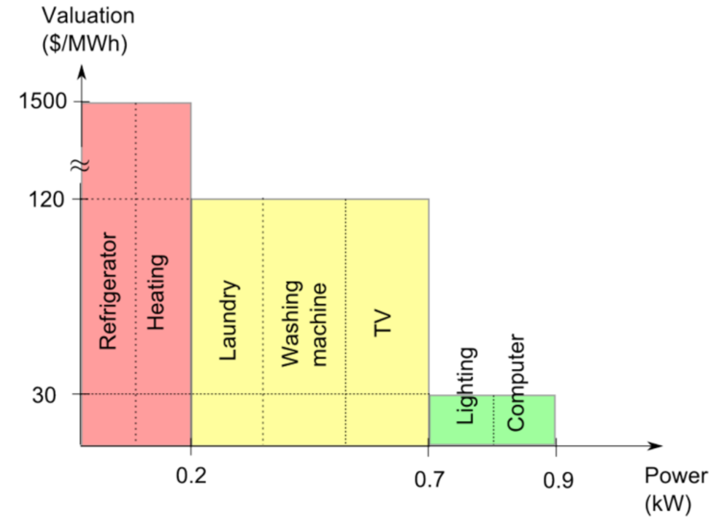


Household «production» theory

Energy demand derived from the demand for:

- services like electricity, hot water, heating
- Industrial production of goods and services

Given market prices, firms choose their inputs to production (e.g. capital and energy) in order to maximize profit or minimize their total production cost. Households also act as producers when doing their optimization:

Two steps:

1. Choose their optimal capital-energy combination (K, E) to produce a service (e.g. car Transportation, T) at the minimum cost
2. Contrast the amount of service (T) with other goods (OG) in order to maximize their utility given their budget constraint

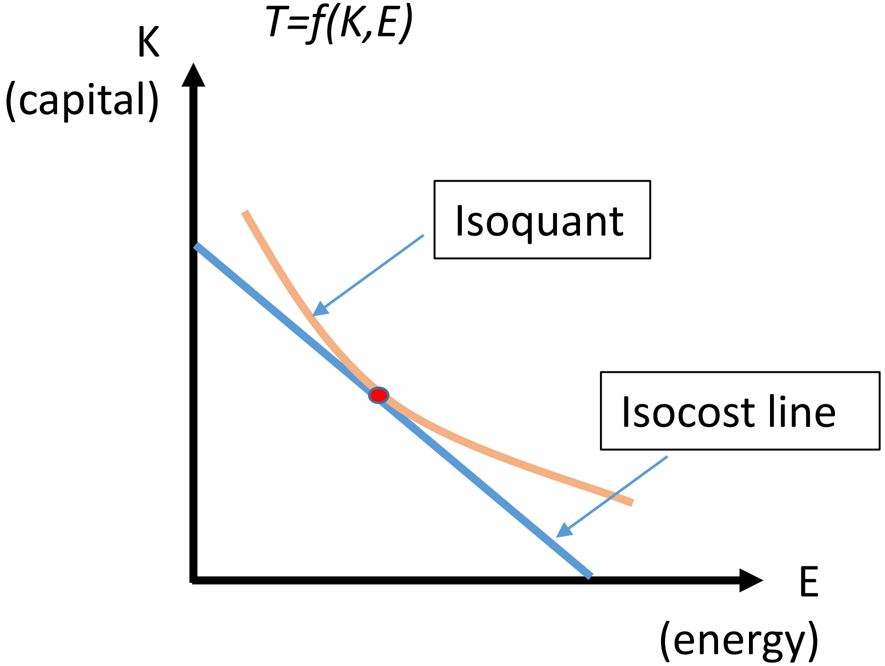
Energy Demand

Household «production» theory

1. Choose their optimal combination (K, E) in to produce a service (e.g. transportation T) at the minimum cost

Production function

T=f(K,E)



$$\min_{\{K,E\}}(p_K\, K + p_E\, E)$$

s.t. $$T = f(K,E)$$

↓

$$K = K(p_K, p_E, T)$$
$$E = E(p_K, p_E, T)$$

↓

$$\mathrm{T}C = TC(p_K, p_E, T)$$

TC transport. cost

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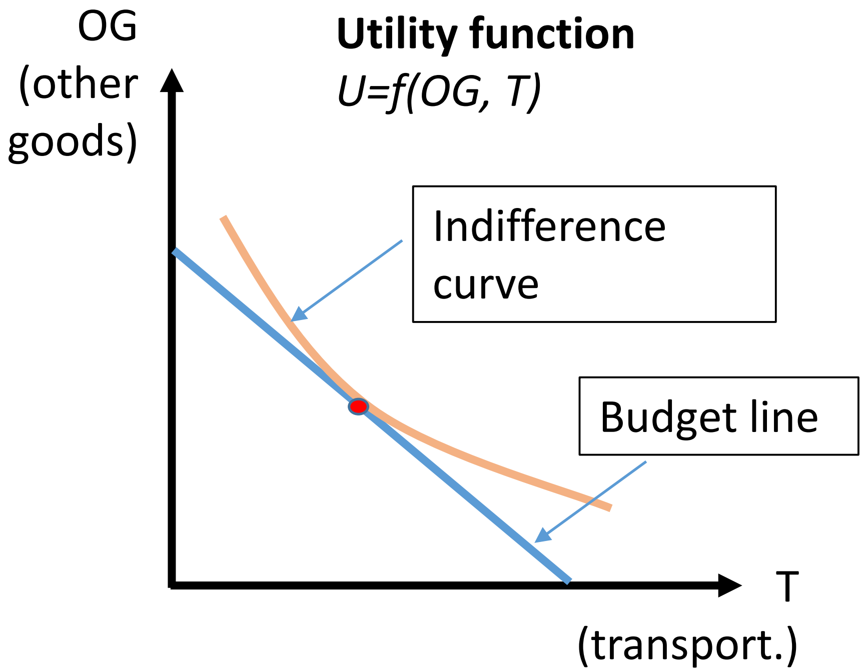
Household «production» theory

2. Contrast the amount of energy service (T) with other goods in order to maximize their utility given their budget constraint (expenditure on goods and services –cannot exceed income *I*)



$$\max_{\{OG,T\}} U = f(OG, T)$$
$$\text{s.t. } TC(p_K, p_E, T) + p_{OG}OG \leq I$$

↓

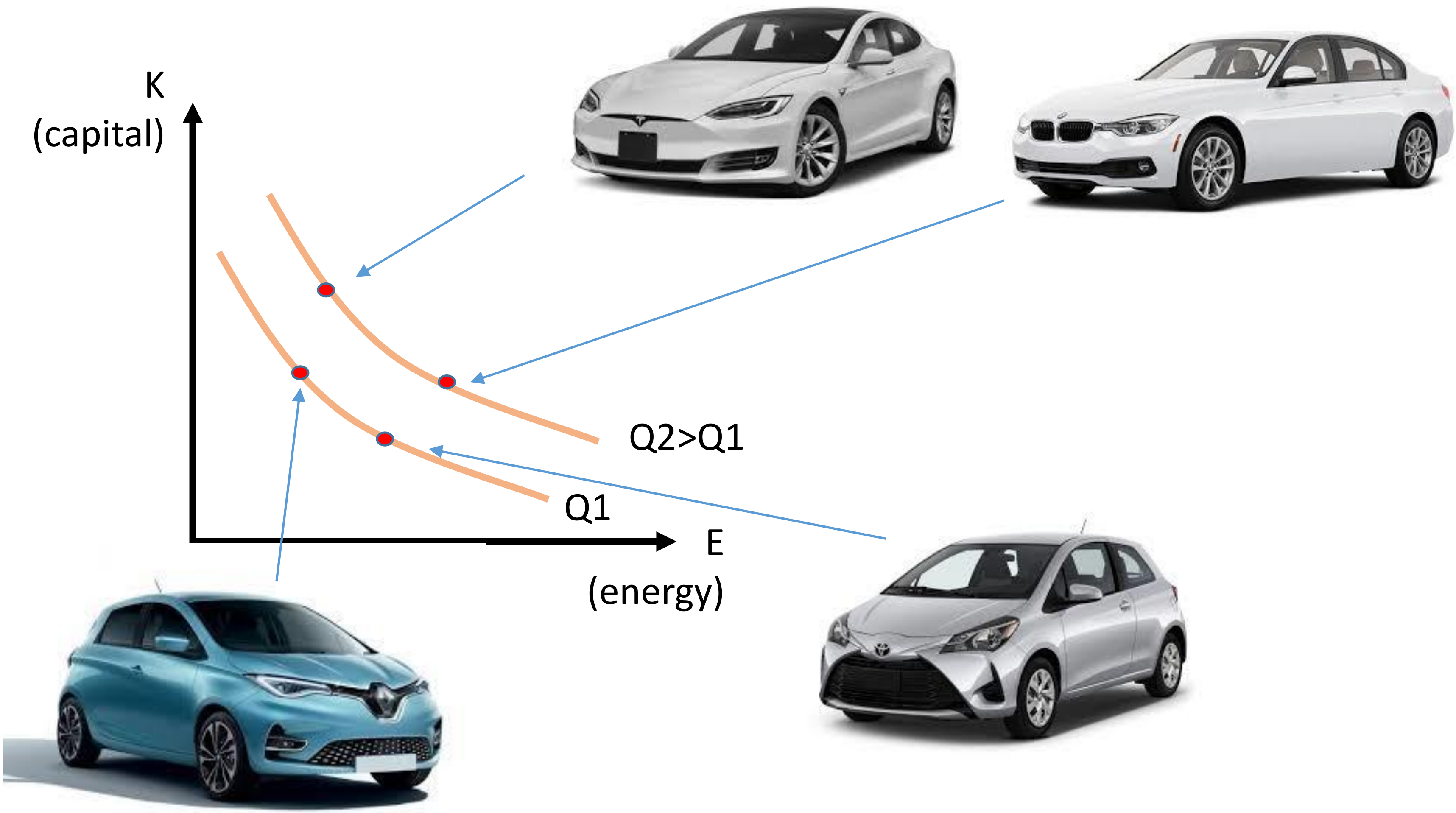
$$T = T(p_K, p_E, p_{OG}, I)$$
$$OG = OG(p_K, p_E, p_{OG}, I)$$

↓

$$K = K(p_K, p_E, p_{OG}, I)$$
$$\boldsymbol{E = E(p_K, p_E, p_{OG}, I)}$$

Energy Demand

What about policy? Example: conventional vs. Electric car



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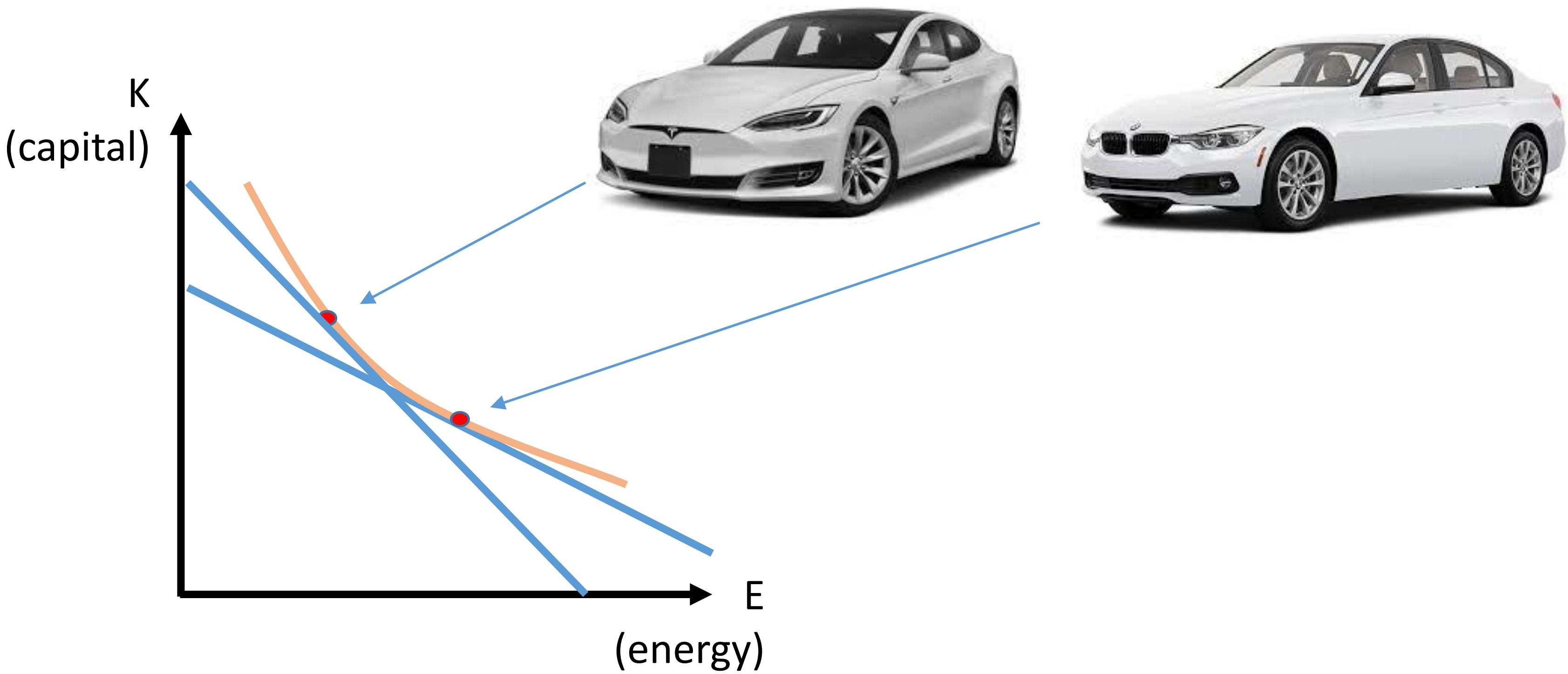
Cost minimization and different relative prices



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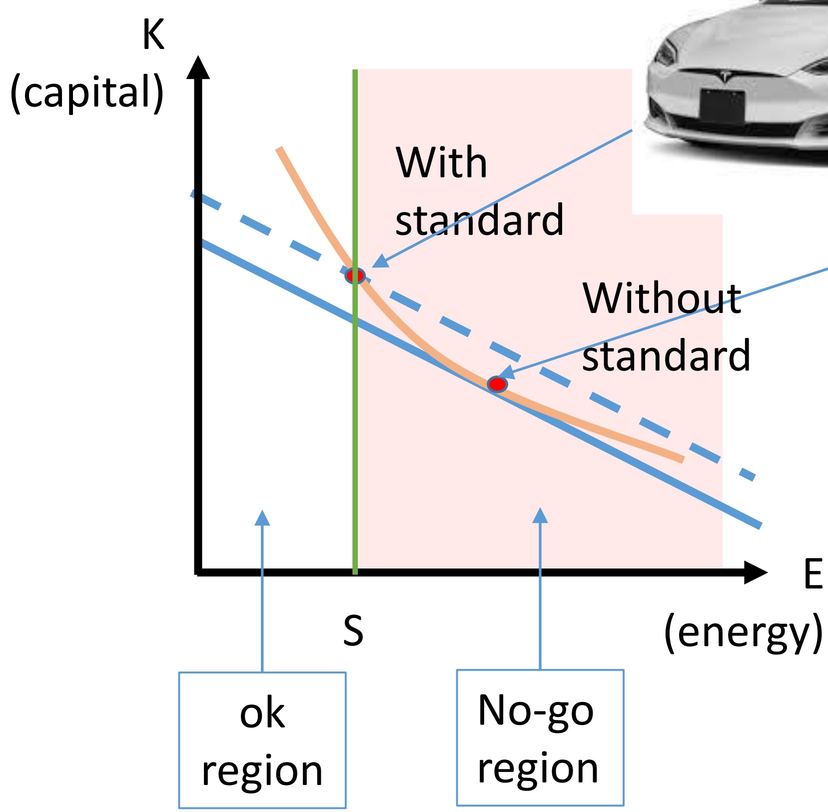
Implications of an emissions standard S (energy consumption E<S)

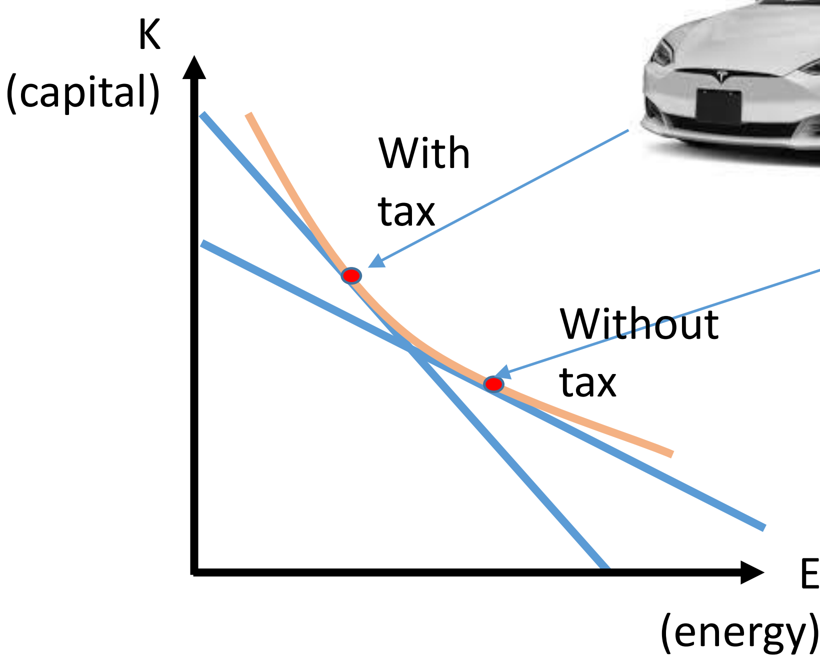


Imposing a standard restricts the choices set and pushes consumers towards the more environmental friendly option.

A standard works as an «infinite» tax on energy consumption above standard but is <u>less efficient</u> because it doesn't raise any revenue for the government!

Energy Demand

Implications of a CO2 tax



Imposing a taxation policy per unit of gasoline increases the relative price of energy and rotates the cost curve

The new equilibrium is the one where the consumer eventually chooses for the less polluting option

Empirical analysis

The specification we use

$$E = E(p_K, p_E, p_{OG}, I, policy, geography, climate, demographics, \dots)$$

Should match both our theory and logic and can be used to infer the different elasticities:

$$\log E = a + \epsilon_E \log p_E + \epsilon_K \log p_K + \epsilon_{OG} \log p_{OG} + \epsilon_I \log I + .. + error$$

- ϵ_E is the own price elasticity, ϵ_K and ϵ_{OG} the cross-price elasticities of capital (e.g. price of cars) and other goods, ϵ_I the income elasticity etc..

- The error term represents the collective influence of any omitted variables, unpredictable human behavior, measurement errors etc. (more in a bit)

Empirical analysis

What we need:

1. Microeconomic theory

2. Data

3. Econometric methods (e.g. OLS regression analysis)

4. Interpretation of results

Econometric regression

Regression
Statistical procedure for quantifying economic relationships, testing hypotheses about them and do forecasting

OLS – ordinary least squares

- In the simplest linear case: $Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \cdots + error$

Here we test how our dependent variable Y (e.g. Energy demand) is influenced by unit changes in the independent variables X_j, with $j = 1,2,..$

- The different coefficients β_j inform us about the change in Y following a change in X_j (holding all else constant), i.e. $\beta_j = \frac{\Delta Y}{\Delta X_j}$. The β_j's are what we are interested in

- Hopefully the different X_j's do not influence one another greatly such that our estimates for β_j's are good enough (I won't go into details in this class)

Econometric regression

The basics of Regression (OLS – ordinary least squares)

- The logarithmic case is most widely used:

$$\log Y = \beta_0 + \beta_1 \log X_1 + \beta_2 \log X_2 + \cdots + error$$

Here we test the relative(%) change of our dependent variable Y (e.g. Energy demand) by relative(%) changes in the independent variables X_j, with $\mathrm{j} = 1,2,..$

- Here $\beta_j = \frac{\Delta \log Y}{\Delta \log X_j} = \frac{\%\ change\ in\ Y}{\%change\ in\ X_j}$ (holding all else constant), which is exactly the elasticity ϵ_j!

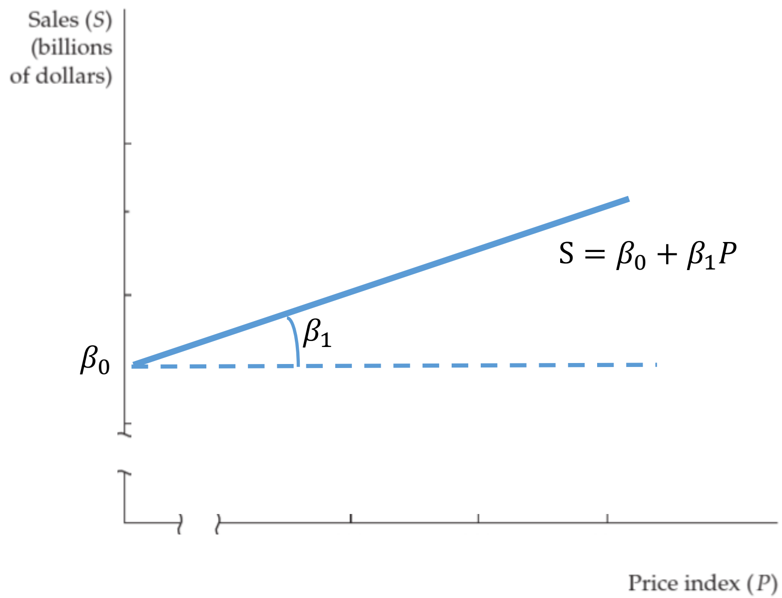
To summarize:

- Linear case: $\beta_j = \frac{\Delta Y}{\Delta X_j} =$ unit change in Y from 1 unit change in Xj
- Logarithmic case: $\beta_j = \frac{\Delta \log Y}{\Delta \log X_j} =$ % change in Y from 1% change in Xj

Estimation

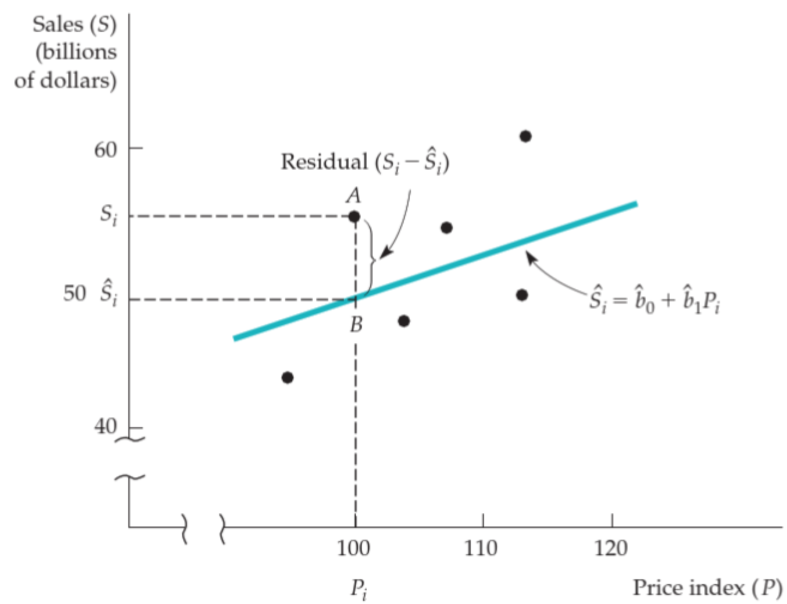
Example Car sales in the US

- Assume that sales S (in billion $) depend only on the price P (measured by a new car price index where 2016 = 100)
- In this simple model $S = \beta_0 + \beta_1 P + error$
- If there was no error term, all observations (data) should fall on the line $S = \beta_0 + \beta_1 P$:



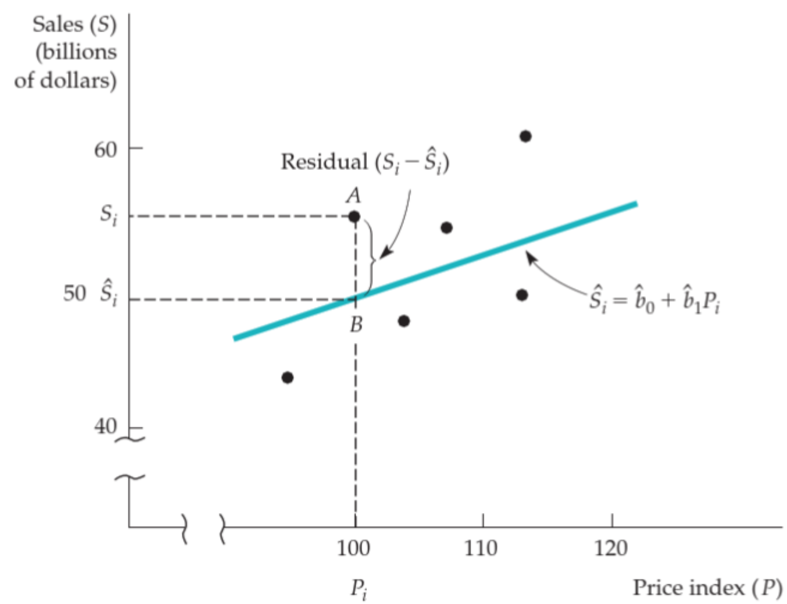
Estimation

- But actually as you see below not all observations fall on the line
- Each observation has a vertical distance from the line, *the residual*
- The «best-fit curve» is the one that *minimizes the sum of squared residuals* between the actual value of *Y* and the *fitted* value of Y (i.e. the line)
- This is the **least squares criterion** (that's why «Ordinary Least Squares»)



Estimation

- The «best-fit curve» is the one that *minimizes the sum of squared residuals* between the actual value of *Y* and the *fitted* value of *Y* (i.e. the line)
- For point (P_i, S_i) e.g. point A, residual is $\hat{e}_i = S_i - \hat{S}_i$ where S_i is the true observation and $\hat{S}_i$ our estimate, i.e., on our fitted curve
- Least squares criterion: $\min\{(\hat{e}_1)^2 + (\hat{e}_2)^2 + \cdots + (\hat{e}_N)^2\}$



Estimation

- For the fitted line $\hat{S} = \hat{\beta}_0 + \hat{\beta}_1 P$ we get $\hat{\beta}_1 = 0.57$. It means that a 1-unit increase in the car price index is associated with $0.57 billion increase in car sales..

- That sounds a bit weird! increasing price increases car sales? Theory ☒

- The model can be improved if we account for other socio-economic factors such as personal income *I* and interest rates *r* (e.g. the 3-month T-bill) :

$$\hat{S} = 51.1 - 0.42\, P + 0.046\, I - 0.84\, r$$

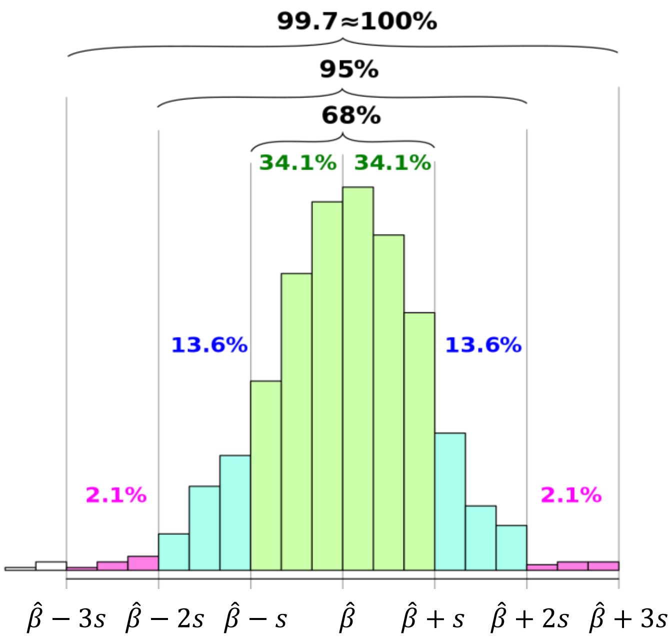
- Now $\hat{\beta}_1 = -0.42$ such that demand is downward sloping. Theory ☑

- In addition a $1 billion increase in US personal income is likely to lead to a $0.42 billion increase in car sales, while a 1% reduction is interest rates leads to $0.84 billion increase in sales (because lending just became cheaper so people can buy a car with a lower interest on their loan)

Confidence intervals

- Of course if we used a <u>different sample</u>, i.e., a different collection of (S, P, I, r) we would have gotten different estimates for the various $\hat{\beta}$'s

- If we continue to collect samples and generate estimates $\hat{\beta}$, for each parameter β we can construct a (approximately normal) distribution with a *mean* (our estimate $\hat{\beta}$) and a measure of dispersion/uncertainty around this mean, <u>*the standard error* (*s*) of the $\hat{\beta}$ coefficient</u>



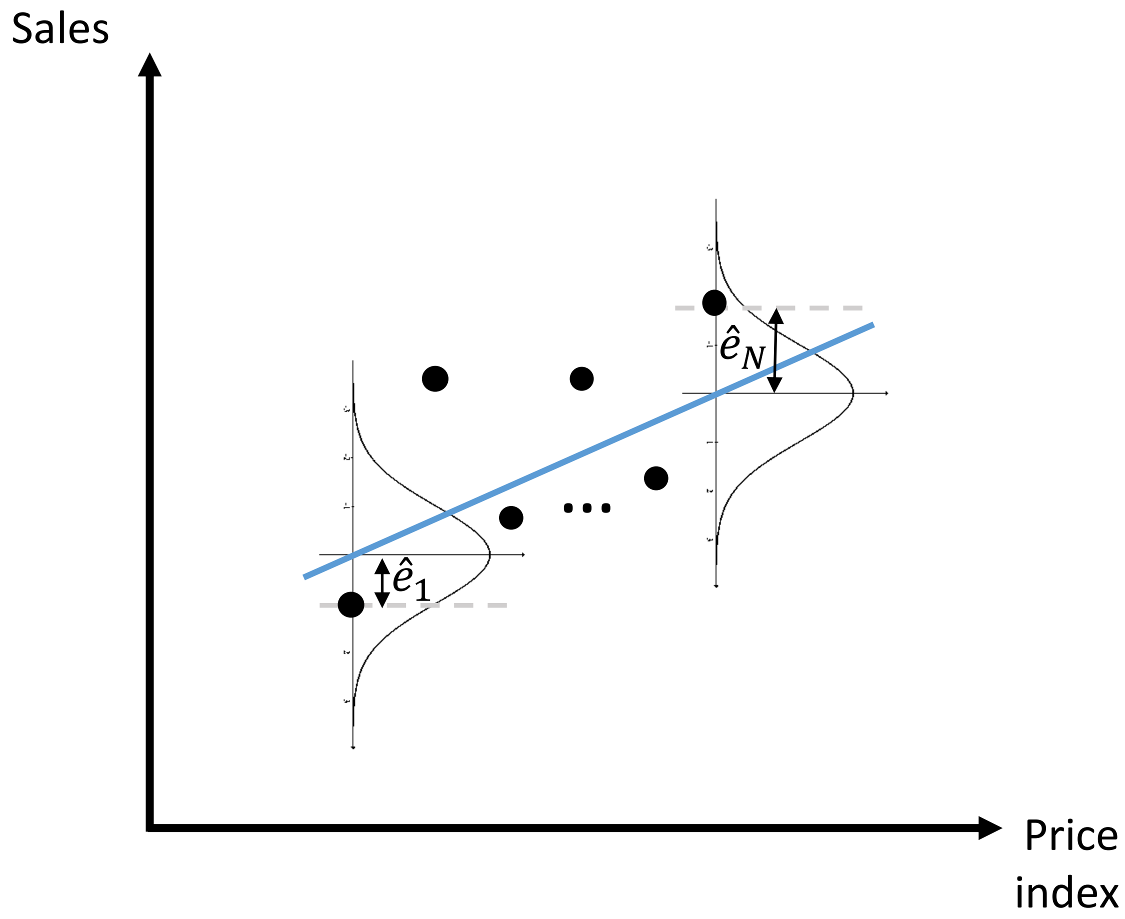
What is the probability that the true value of β lies within certain range of our estimate?

$$\Pr(\hat{\beta} - s \le \beta \le \hat{\beta} + s) = 0.6827$$
$$\Pr(\hat{\beta} - 2s \le \beta \le \hat{\beta} + 2s) = 0.9545$$
$$\Pr(\hat{\beta} - 3s \le \beta \le \hat{\beta} + 3s) = 0.9973$$

Actually what we mostly use is:
$$\Pr(\hat{\beta} - 1.96s \le \beta \le \hat{\beta} + 1.96s) = 0.95$$

→ 95% confidence interval

Confidence intervals

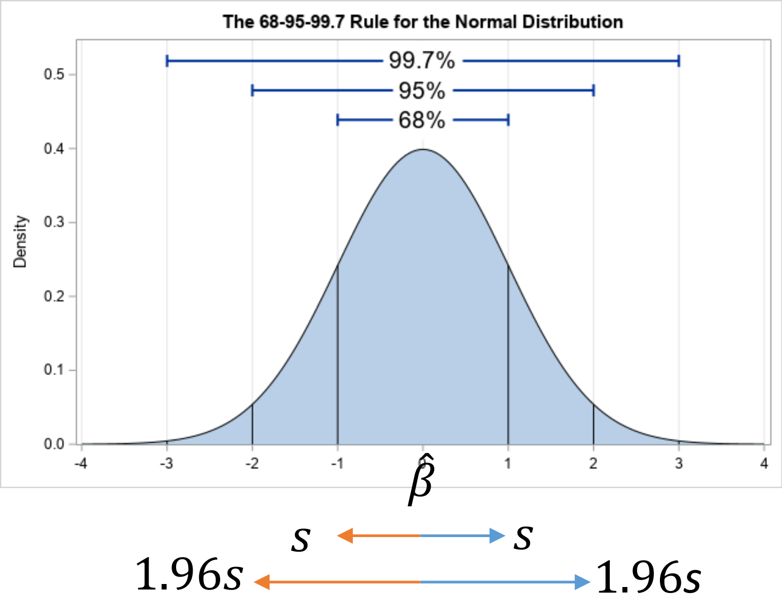


Confidence intervals

- The area within 1.96 std. errors of the mean is equal to 95% of the total area
- Can we construct an interval around our estimate $\hat{\beta}$ such that there is a 95% probability that the true parameter β lies within that interval?

95% confidence interval

$$\boldsymbol{\hat{\beta} \pm 1.96 \times std.\, error\ of\, \hat{\beta}}$$



t-statistics

- If the 95% confidence interval contains 0 then the true parameter β may indeed be 0, thus not influencing our explanatory variable; then if our estimate is not 0 then it’s wrong.

- We can test this hypothesis that a true parameter is actually 0 by looking at its t-statistic:

$$t = \frac{\hat{\beta}}{std.error\ of\, \hat{\beta}}$$

- If |t|<1.96 the 95% confidence interval around $\hat{\beta}$ must include 0. In this case we cannot reject the hypothesis that the true β is zero and the estimate is *not statistically significant*

Example

Suppose in the previous example we had

$$\hat{S} = 51.1 \quad - 0.42\,P \quad + 0.046\,I \quad - 0.84\,r$$
$$\quad (9.4) \quad (0.13) \quad (0.006) \quad (0.32)$$
$$t\ stat: \quad 5.44 \quad -3.23 \quad 7.67 \quad -2.63$$

(In parentheses the std. error of each estimate $\hat{\beta}$, below their t-statistics)

We are 95% certain about the following estimates

P: $\hat{\beta}_P = -0.42 \pm 1.96 \times 0.13,$ → $\beta_P \in [-0.67, -0.17]$
I: $\hat{\beta}_I = 0.046 \pm 1.96 \times 0.006,$ → $\beta_I \in [0.034, 0.058]$
r: $\hat{\beta}_r = -0.84 \pm 1.96 \times 0.32,$ → $\beta_r \in [-1.47, -0.21]$

None of the ranges above includes 0, such that all estimates are statistically significant at the 5% level (95% certain that the true value of the estimate lies within the range [... , ...]).

Goodness of fit

Not the std. error of the $\hat{\beta}$ estimators

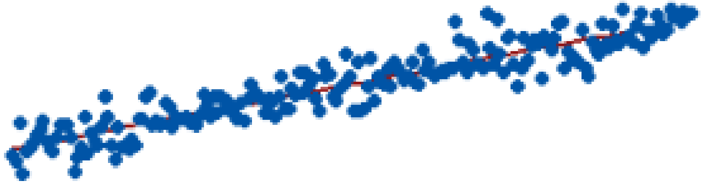
- Reported results inform us about how closely the regression line fits the data
- The **standard error of the regression** (SER) is an estimate of the std. deviation of the regression's error term e
  - SER = 0 → all data lie on the regression line
  - SER > 0 → the larger the SER the poorer the fit of the data
  - SER is a measure of the average distance of the estimates $\hat{Y}$ from the true Y:

$$SER = \sqrt{\frac{\sum_i^N \left(S_i - \hat{S}_i\right)^2}{N}} = \sqrt{\frac{\sum_i^N e_i^2}{N}}$$

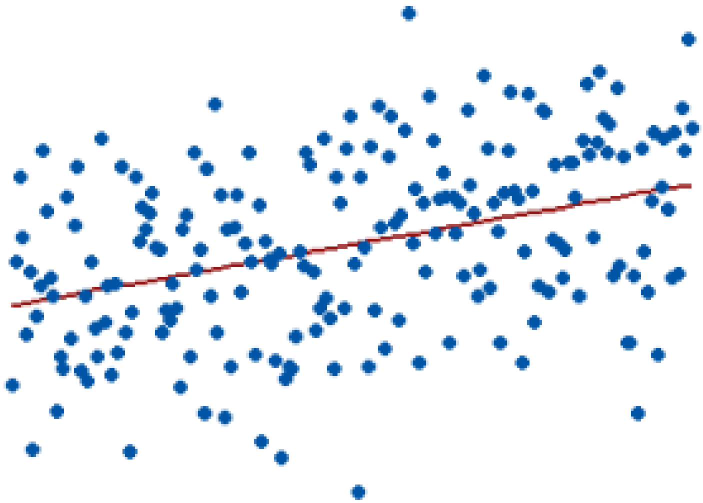
- **R-squared (R^2):** the % of variation in the dependent variable (Y) that is explained by all explanatory variables (different X's)
  - R^2=0 → the chosen explanatory vars cannot explain any variation in Y
  - R^2=1 → the chosen explanatory vars explain 100% of the variation in Y

Goodness of fit

R^2 - good and bad fit



R^2 = 0.85 = 85%



R^2 = 0.15 = 15%

Goodness of fit

Important: high R^2 doesn't necessarily mean that all variables included in the model are the right ones.

Additional tests needed (will not go into detail):

- Do we look for a linear relationship when there is actually a non-linear one?
- Do we look in the right place? E.g. do we expect prices of wheat to influence vastly car sales? Theory?
- Is the *specification* of the equation correct? E.g. do we include all important variables?
- Are the independent variables independent from one another (*multicollinearity*)? A correlation between the X's below 0.4 would be good.
- Adding or removing one or two data points from our sample results in major difference in the estimated coefficients $\hat{\beta}$? Then the estimation is not *robust.*
- Is there another relationship between Y and the X's that we do not account for by our model? Do we maybe need another equation?
- Does the std. error increase/decrease as my independent var increase/decrease? Not good -> heteroscedasticity

OLS using MS Excel

1. Import the data (each variable is a column)
2. Choose a model specification (e.g. linear $y=a+bx$ or log-log $logy=\alpha+\beta\ logx$)
3. Prepare your data in the right formal for the econometric software
4. Check variables for data consistency
5. Compute correlation matrix to check for multi-collinearity
6. Estimation of the model using OLS
7. Read results and check for significance at 5% level

OLS using MS Excel

Example: Electricity demand in Great Britain for 1937

1. Import the data (each variable is a column)

Town number	Consumption Q (kWh)	Income p.c. I (£/year)	Electricity Price 1936 p36 (p./kWh)	Gas Price 1936 g36 (p./m3)	Capital K (kWh)
1	1772	629	0.33	4.2	0.2
2	532	279	0.48	10.5	0.4
3	2133	788	0.55	5.5	1.16
4	874	486	0.63	7.1	0.31
5	758	403	0.68	9	0.29
…	…	…	…	…	…
…	…	…	…	…	…
40	632	323	0.5	8.3	0.45
41	767	444	0.5	8.3	0.53
42	1877	524	0.5	8.9	0.51

2. Choose a model specification (e.g. linear *y=a+bx* or log-log *logy=α+β logx*)

E.g.: $$\log Q = \beta_0 + \beta_{p36} \log P36 + \beta_{g36} \log G36 \; + \beta_I \log I + \beta_K \log K + e$$

OLS using MS Excel

3. Prepare your data in the right formal for the econometric software

- Here prices are measured in pence/kWh, while income in pounds. At the time 1£ hat 20 Shillings and 1 Shilling was equal to 12 p. → multiply prices by x 20 x 12 (not needed actually. But our numbers look nicer this way. Anyway when measuring elasticities we care about %-changes so units don't play a role). Same for gas price.
- We will do a log-log regression such that variables should be in logs (=LN(Cell Num.))

Town number	Consumption Q (kWh)	Income p.c. I (£/year)	Electricity Price 1936 p36 (p./kWh)	Gas Price 1936 gas36 (p./m3)	Capital K (kWh)		logQ	log_I	logP36	logG36	logK
1	1772	629	0.33	4.2	0.2		7.479864131	6.44413	=LN(D2*20*12)	1.43508	-1.60944
2	532	279	0.48	10.5	0.4		6.276643489	5.63121	-0.733969175	2.35138	-0.91629
3	2133	788	0.55	5.5	1.16		7.665284718	6.6695	-0.597837001	1.70475	0.14842

↓

Town number	logQ	log_I	logP36	logG36	logK
1	7.479864131	6.444131	4.371976299	6.915723	-1.60944
2	6.276643489	5.631212	4.746669748	7.832014	-0.91629
3	7.665284718	6.669498	4.882801923	7.185387	0.14842
4	6.773080376	6.186209	5.018603464	7.440734	-1.17118
5	6.630683386	5.998937	5.094976443	7.677864	-1.23787
6	7.595387279	6.593045	4.787491743	7.367709	-0.31471

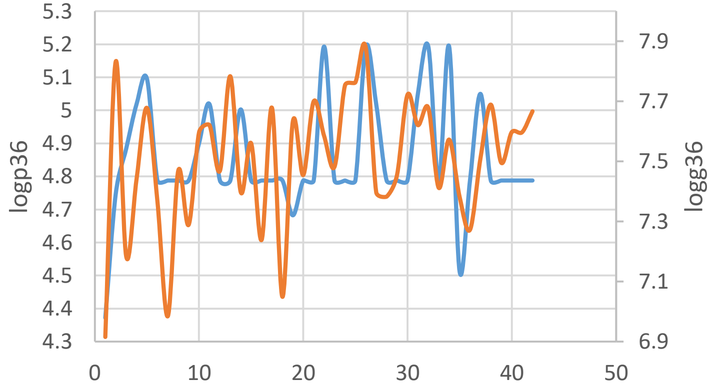
OLS using MS Excel

4. Check variables for data consistency:

- No non-numerical of missing values in our dataset – that's good!

- The independent variables should exhibit enough but not extreme variation:
  - Otherwise how can we talk about % changes and elasticities?
  - If variation is extreme we talk about rare events that should be *controlled for*

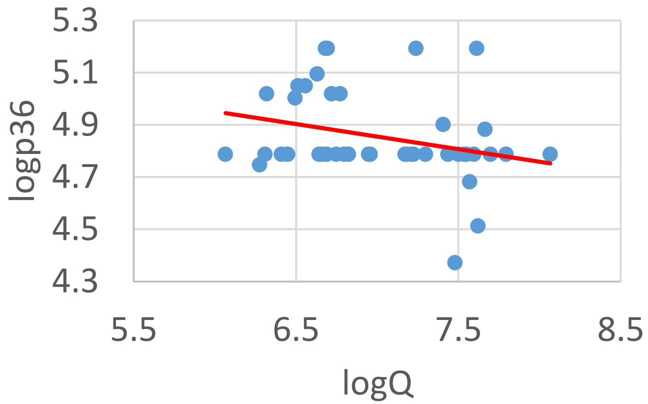
- We can see that by scatter plot (Insert>Scatter (X,Y) where X is the number of towns and Y are logp36 and logpg36). Moderate variation - looks good:

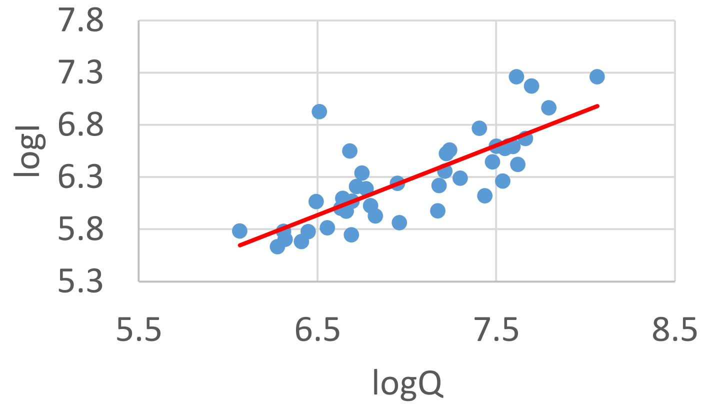


To do a plot: Insert Tab > Choose your chart type > Insert Data from Columns

OLS using MS Excel

- Moreover our data should follow theory otherwise there something wrong. Data? Theory?





a) Prices and Quantities move in the opposite direction: that's good!
b) Income is positively correlated with consumption: good as well!

We don't need to do a graph for every (X,Y) combination. We can instead calculate the correlation matrix (step 5)

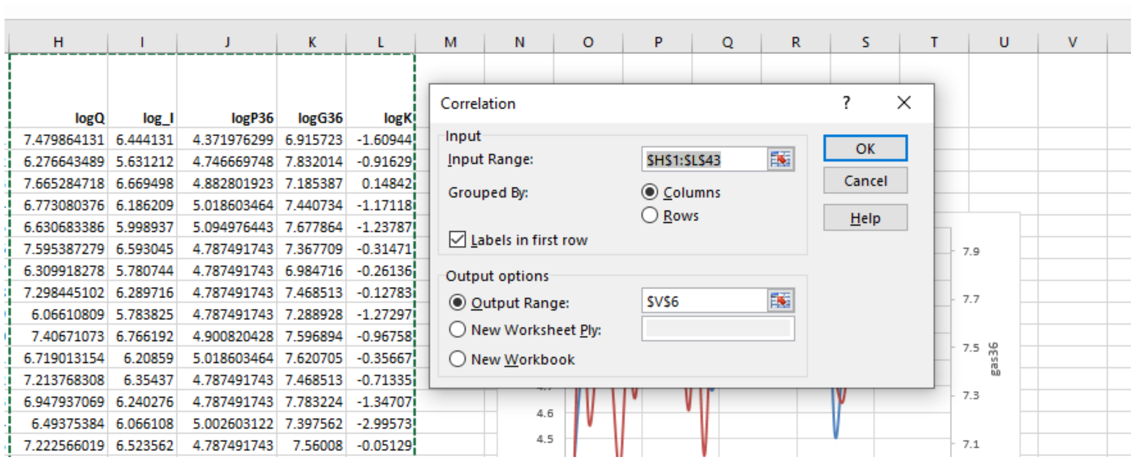
Correlation [-1,1]: how well pairs of variables are related – co-move
Corr=1→ perfectly correlated, Corr=0 → no-correlation (red line horizontal), Corr=-1 → perfectly negatively correlated. Watch out!! **No causality inference**

OLS using MS Excel

5. Compute correlation matrix to check for multi-collinearity

Data Analysis Tool should be activated (go to File > Options > Add ins > Analysis ToolPack)!

Data Tab > Data Analysis > Correlation



Input range: choose your columns including names in first row (check box labels in first row). *Output range* is where your table will be created. I chose its left-up corner to start at V6:

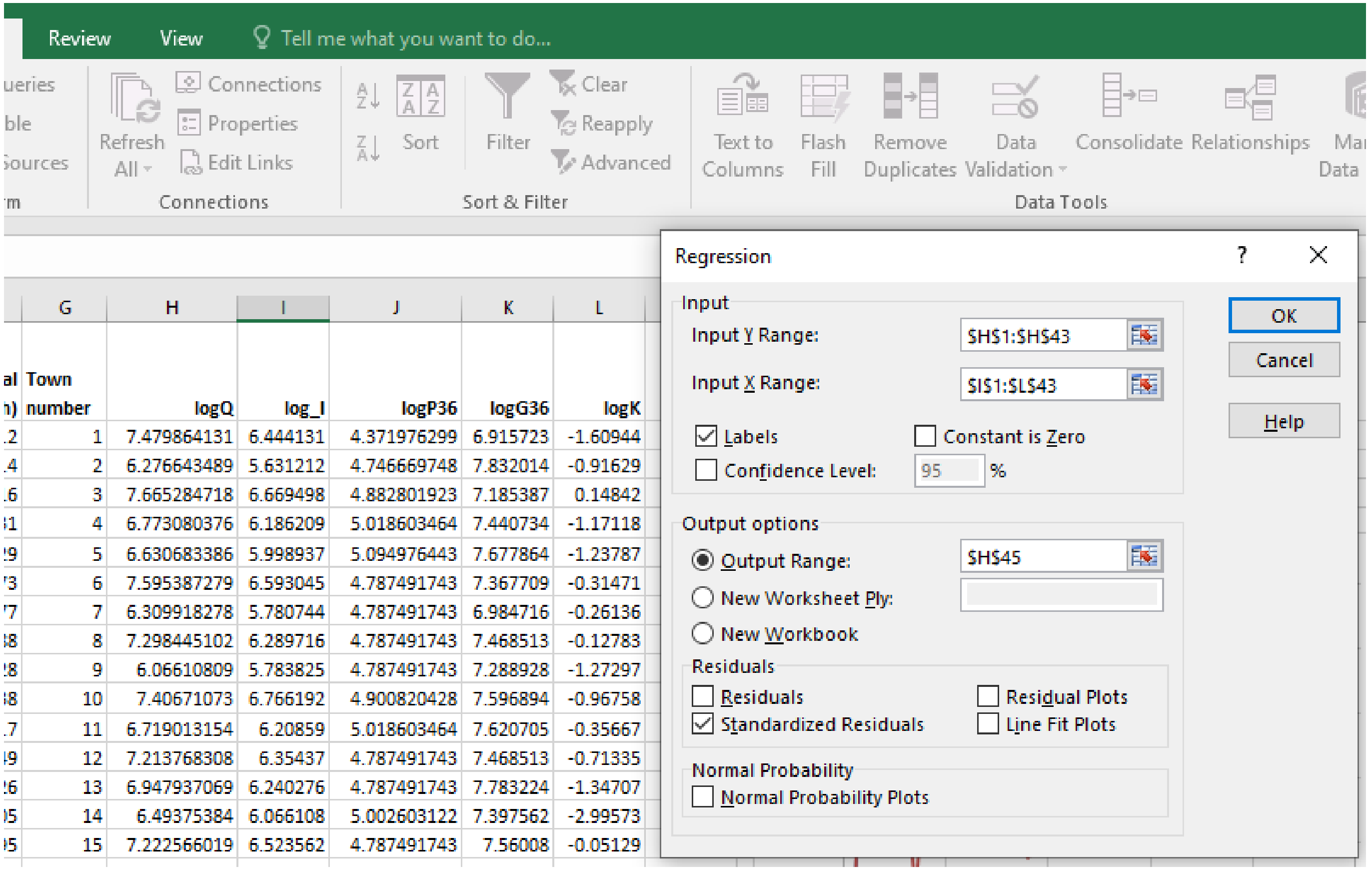
	logQ	logI	logP36	logG36	logK
logQ	1				
logI	0.77383	1			
logP36	-0.28376	0.078419	1		
logG36	0.021677	0.121292	0.364029	1	
logK	0.109793	-0.335	-0.15794	-0.00212	1

No two explanatory variables are perfectly correlated. That’s good! Otherwise we would have a multi-collinearity issue: can’t distinguish which X variable influences our Y

OLS using MS Excel

6. Estimation of the model using OLS Regression

Data Tab > Data Analysis > Regression



OLS using MS Excel

6. Estimation of the model using OLS Regression

- Input Y Range: our dependent variable (including 1st line), i.e., log Q
- Input X Range: our independent variables, i.e., logP36, logG36, …
- Check box labels: keeps the names from the 1st line
- Output Range: where your Regression table will be shown. Here it starts at cell H45

Clipboard | Font | Alignment | Number

S48

	A	B	C	D	E	F	G	H	I	J	K	L
40	39	3183	1422	0.5	7.5	0.17	39	8.065579427	7.25981961	4.7874917	7.4955	-1.772
41	40	632	323	0.5	8.3	0.45	40	6.448889394	5.777652323	4.7874917	7.5969	-0.799
42	41	767	444	0.5	8.3	0.53	41	6.642486801	6.095824562	4.7874917	7.5969	-0.635
43	42	1877	524	0.5	8.9	0.51	42	7.537430037	6.261491684	4.7874917	7.6667	-0.673

SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.915848423
R Square	0.838778333
Adjusted R Square	0.821348964
Standard Error	0.213527568
Observations	42

SER

ANOVA

	df	*SS*	*MS*	*F*	*gnificance F*
Regression	4	8.776744	2.1942	48.124	4E-14
Residual	37	1.6869788	0.0456		
Total	41	10.463723			

	Coefficients	*Standard Erro*	*t Stat*	*P-value*	*ower 95%*	*Jpper 95%*	*ower 95.0%*	*pper 95.0%*
Intercept	4.457711471	1.3328185	3.3446	0.0019	1.7572	7.1583	1.7572	7.1583
log_I	1.065019385	0.0818958	13.005	2E-15	0.8991	1.231	0.8991	1.231
logP36	-0.90200665	0.2122968	-4.249	0.0001	-1.332	-0.472	-1.332	-0.472
logG36	0.05139437	0.1653462	0.3108	0.7577	-0.284	0.3864	-0.284	0.3864
logK	0.18424559	0.0354658	5.195	8E-06	0.1124	0.2561	0.1124	0.2561

Std. error of $\hat{\beta}$

RESIDUAL OUTPUT

Observation	*Predicted logQ*	*Residuals*	*dard Residuals*
1	7.436181902	0.0436822	0.2153
2	6.407232416	-0.1305889	-0.644
3	7.553170597	0.1121141	0.5527
4	6.685956406	0.087124	0.4295
5	6.41751864	0.2131647	1.0509
6	7.481756997	0.1136303	0.5602
7	6.606785783	-0.2968675	-1.464

OLS using MS Excel

7. Interpret results. Do they make sense?

SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.92
R Square	0.84
Adjusted R Squa	0.82
Standard Error	0.21
Observations	42.00

ANOVA

	df	SS	MS	F	Significance F
Regression	4.00	8.78	2.19	48.12	0.00
Residual	37.00	1.69	0.05		
Total	41.00	10.46			

	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%
Intercept	4.46	1.33	3.34	0.00	1.76	7.16
log_I	1.07	0.08	13.00	0.00	0.90	1.23
logP36	-0.90	0.21	-4.25	0.00	-1.33	-0.47
logG36	0.05	0.17	0.31	0.76	-0.28	0.39
logK	0.18	0.04	5.20	0.00	0.11	0.26

Resulting multivariate OLS regression (check column *Coefficients*):

$$\log Q = 4.46 - 0.9 \log P36 + 0.05 \log G36 + 1.07 \log I + 0.18 \log K$$

OLS using MS Excel

7. Interpret results. Do they make sense?

Resulting multivariate OLS regression
$$\log Q = 4.46 - 0.9 \log P36 + 0.05 \log G36 + 1.07 \log I + 0.18 \log K$$

- Elasticities: $\epsilon_P = -0.9\ (own\ price), \epsilon_{P,G} = 0.05\ (cross\ price)$

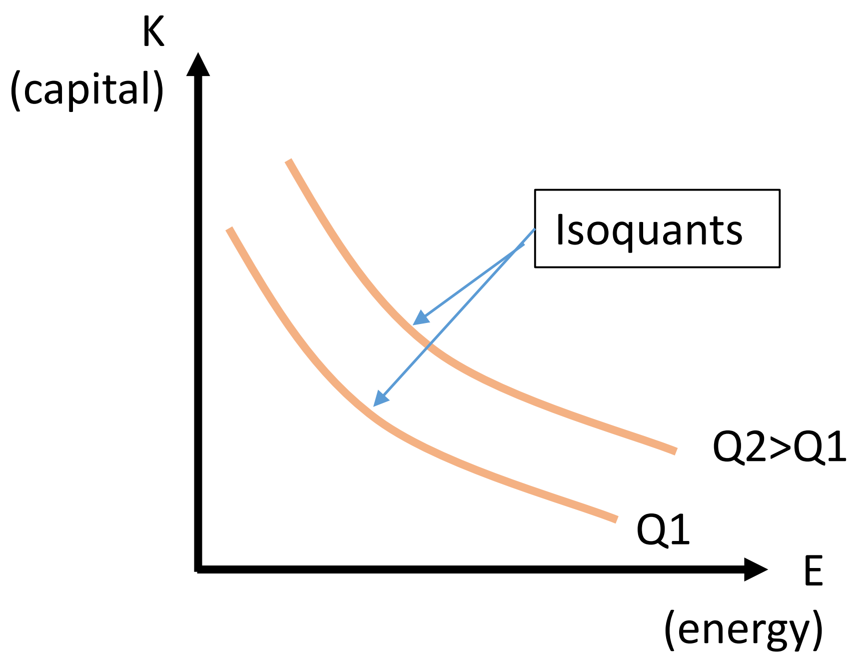
Question: Why is cross price elasticity positive? Positive cross-price elasticity means that when the price of gas goes up, so does the electricity price (gas is used for electricity production).

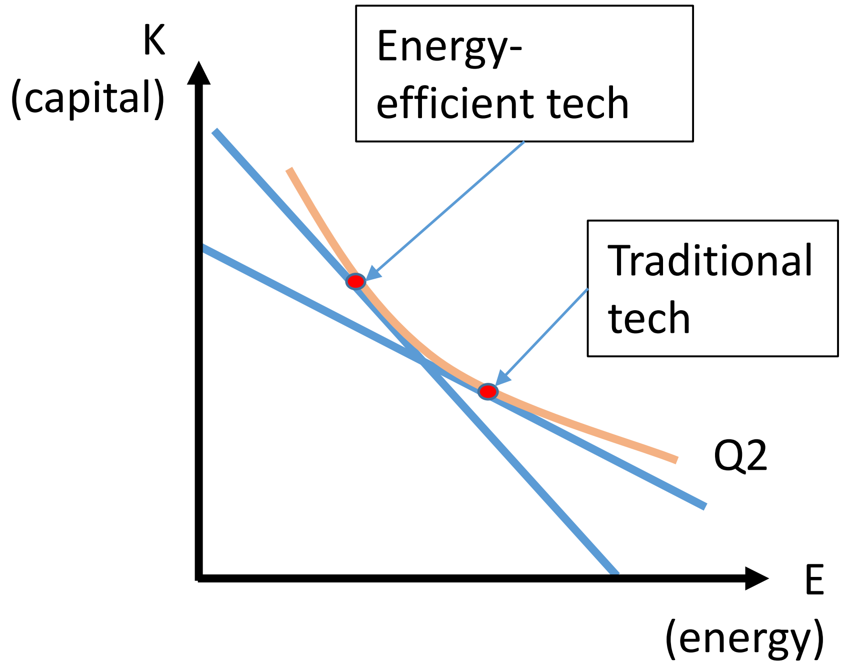
- What about significance? (remember: if |t|<1.96 – no go)

Since t stat for gas price is 0.31 the estimation is not significant. Also seen by the 95% confidence intervals: they include 0. So we cannot reject the null hypothesis that the coefficient for gas is zero.

Energy Demand by firms

Cost minimization of the producer firm using capital and energy as inputs:





How easily can we substitute energy with capital?

→ Elasticity of substitution (Hicks, 1932)

Energy Demand by firms

Firm production theory

In general, the production function of a firm can be written as $Q = f(K, L, E, M, \ldots)$, with K capital, L labor, E energy, M raw materials. Other factors can be knowledge capital (e.g. patents), or specialized human capital

The objective of the firm is to minimize cost of producing Q:

$$\min(p_K\, K + p_L\, L + p_E\, E) \;\; such\ that\ Q = f(K, L, E)$$

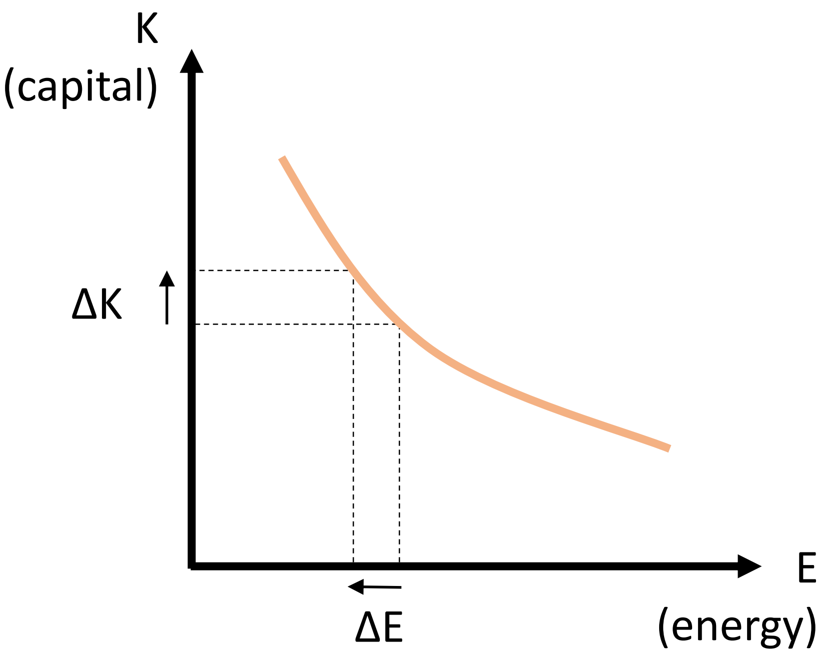
with p_K, p_L, p_E market prices for capital, labor, energy. In many models we may use the interest rate *r* as the unit cost of capital and we may write *w* for the price of labor, i.e., the wage rate.

Same procedure as in household production theory gives

K=K(p_K, p_L, p_E,Q), L=L(p_K, p_L, p_E,Q), ***E=E($\boldsymbol{p_K}$, $\boldsymbol{p_L}$, $\boldsymbol{p_E}$,Q)***

Elasticity of factor substitution

Elasticity of substitution in production measures the relative change in the demand of any two factors of production due to changes in their relative prices:



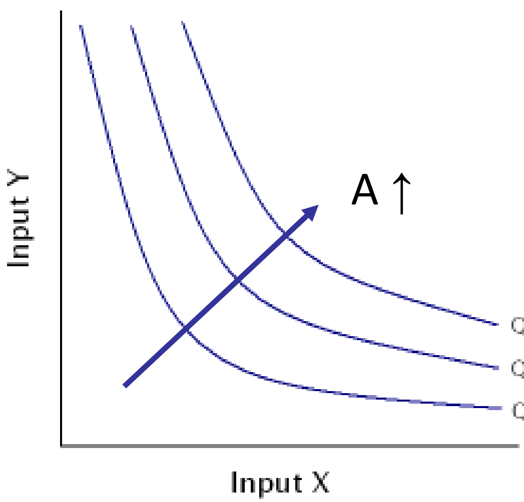
Elasticity of substitution $\sigma = -\frac{\frac{\Delta(E/K)}{E/K}}{\frac{\Delta(pE/pK)}{pE/pK}}$

how much percent less of E relatively to K the firm will use if E becomes $\frac{\Delta(p_E/p_K)}{p_E/p_K}$ *percent more expensive, keeping output Q constant*

Of course same reasoning applies to consumers

Intuition: how easily can we substitute K for E, keeping output constant?

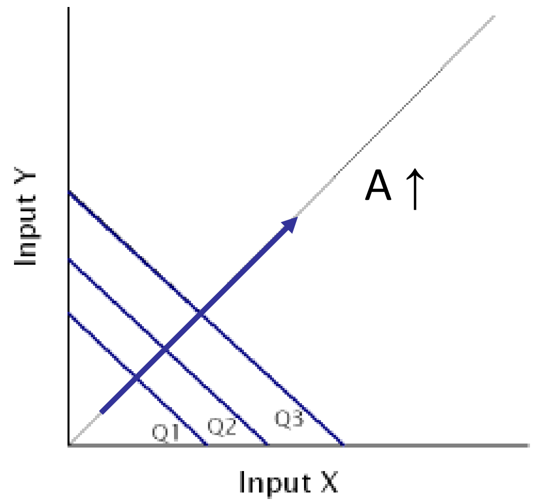
Elasticity of input substitution



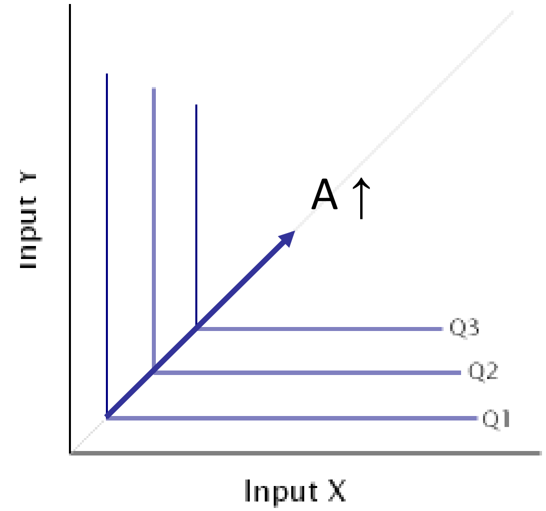
$0 < \sigma < \infty$

$0 < \sigma < 1$ complements

$\sigma > 1$ substitutes



$\sigma \to \infty$ perfect subst.



$\sigma \to 0$ no substitution perfect complem.

The arrow shows the technology expansion path: assume that $\mathrm{A}_1 < \mathrm{A}_2 < \mathrm{A}_3$, then for the same combination $\{\mathrm{X}, \mathrm{Y}\}, \mathrm{Q}_1 < \mathrm{Q}_2 < \mathrm{Q3}$

Elasticity of factor substitution

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Capital–energy substitution: Evidence from a panel of Irish manufacturing firms ☆

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ABSTRACT

We use a translog cost function to model production in the Irish manufacturing sector over the period from 1991 to 2009. We estimate both own- and cross-price elasticities and Morishima elasticities of substitution between capital, labour, materials and energy. We find that capital and energy are substitutes in the production process. Across all firms we find that a 1% rise in the price of energy is associated with an increase of 0.04% in the demand for capital. The Morishima elasticities, which reflect the technological substitution potential, indicate that a 1% increase in the price of energy causes the capital/energy input ratio to increase by 1.5%. The demand for capital in energy-intensive firms is more responsive to increases in energy prices, while it is less responsive in foreign-owned firms. We also observe a sharp decline in firms' responsiveness in the first half of the sample period.

Ex-ante vs ex-post analysis

- Regressions:
  - evaluate the interdependence and the causality of variables
  - Estimate elasticities – very useful!!
  - ex-post analysis of various policies
  - forecast how certain variables will behave in the future

Big drawback of econometric regressions is the need of large datasets

- In many applications we need to model the reaction of more complex economic systems with more interlinkages

- Calibrated numerical models using explicit theory can be handy

- Using calibrated models we may capture first-order responses of complex systems and do ex-ante policy evaluation, with little data

Tax incidence revisited: an algebraic model

Example: Effect of environmental taxation on international coal market

1. Find data on base year production, consumption and prices of coal for countries that collectively represent global coal supply and demand

2. Calibrate model to these data

3. Perform *counterfactual analysis* (what-if analysis) by applying taxes in a subset of regions – e.g. Annex B member states of a given environmental agreement

4. Assume coal supply is price-elastic (in the range 1 to 2)

5. Assume coal demand is price in-elastic (around 0.5)

6. Evaluate the *global leakage rate:*

$$l = \frac{\%\ increase\ in\ coal\ use\ in\ non-Annex\ B\ states}{\%\ decrease\ in\ coal\ use\ in\ Annex\ B\ states}$$

Tax incidence revisited: an algebraic model

Elasticities: $\epsilon_S = \frac{\frac{\Delta Q_S}{Q_S}}{\frac{\Delta P}{P}}, \epsilon_D = \frac{\frac{\Delta Q_D}{Q_D}}{\frac{\Delta P}{P}}$

With $\Delta Q = Q - Q_0$ and Q_0 being the *reference quantity* for *reference price* P_0, (equilibrium price-quantity) i.e. when $P = P_0$ then $Q = Q_0$. Assume linear supply and demand curves and solve for Q:

$$Q_j = Q_{0j}\left(1 + \epsilon_j\left(\frac{P_j}{P_{0j}} - 1\right)\right)$$, for j={S,D}

Note: For calibrated policy analysis the elasticities are *model inputs.* In econometric models they are *model outputs* → *Need for both approaches*

Tax incidence revisited: an algebraic model

The basic structure of the model is summarized in the equation:

$$\sum_r S_r(p) = \sum_r D_r(p, t_r)$$

The index r counts "r"egions. Moreover: p is the world market price of coal, $S_r(p)$ is the coal supply in region r, t_r is a region-specific tax on coal, $D_r(p, t_r)$ is region's r coal demand. The above states that **in equilibrium global supply must match global demand**

With linear supply and demand we may have:

$$S_r(p) = a_r + b_r\, p$$

and

$$D_r(p, t_r) = \alpha_r - \beta_r(p + t_r)$$

We start off imposing the tax on demand; we know that it may well be that suppliers pay the tax in equilibrium (depending on the elasticities)

Calibrated models using MS Excel

3	Equilibrium P/P0	1								
4	Sq. Deviation	5062500								
5	leakage rate	#DIV/0!								
6										
7	**Countries**	**Base year supply-demand and elasticities**				**Policy**	**Equilibrium values**		**Change in demand**	
8		**S0**	**D0**	**εS**	**εD**	**t**	**S**	**D**	**Increase by non-taxed members**	**Decrease by taxed members**
9	China	24333	23606	1.5	-0.5	0	24333	23606	0	0
10	USA	22623	22657	1.5	-0.5	0	22623	22657	0	0
11	Australia	6664	2098	1.5	-0.5	0	6664	2098	0	0
12	India	6065	6483	1.5	-0.5	0	6065	6483	0	0
13	SouthAfrica	5292	3396	1.5	-0.5	0	5292	3396	0	0
14	Russia	5147	4880	1.5	-0.5	0	5147	4880	0	0
15	...	...	...	...	...	...	...	...	...	...

S0, D0 the base year supply – demand (i.e. $Q_{0S} = S_0$, etc.)

Equilibrium values follow $Q_j = Q_{0j}\left(1 + \epsilon_j\left(\frac{P_j}{P_{0j}} - 1\right)\right)$, for j={S,D}

Note that price and tax are in relative to P0 terms: e.g. t=1 means a tax equivalent to a 100% increase in P0.

Our criterion is to **minimize square deviation**: $\Delta = \left(\sum_r (S_r - D_r)\right)^2$

Calibrated models using MS Excel

3	Equilibrium P/P0	0.94493739363986								
4	Sq. Deviation	=(G44-H44)^2								
5	leakage rate	=SUM(I9:I43)/SUM								
6										
7	**Countries**		**Base year supply-demand and elasticities**			**Policy**	**Equilibrium values**		**Change in demand**	
8		**S0**	**D0**	**εS**	**εD**	**t**	**S**	**D**	**Increase by non-taxed members**	**Decrease by taxed members**
9	China	24333	23606	1.5	-0.5	0	=B9*(1+D9*(B3-1))	=C9*(1+E9*((B3+F9)/1-1))	=IF(F9=0,H9-C9,0)	=IF(F9<>0,C9-H9,0)
10	USA	22623	22657	=D9	=E9	0	=B10*(1+D10*(B3-1))	=C10*(1+E10*((B3+F10)/1-1	=IF(F10=0,H10-C10,0)	=IF(F10<>0,C10-H10,0)
11	Australia	6664	2098	=D10	=E10	0	=B11*(1+D11*(B3-1))	=C11*(1+E11*((B3+F11)/1-1	=IF(F11=0,H11-C11,0)	=IF(F11<>0,C11-H11,0)
12	India	6065	6483	=D11	=E11	0	=B12*(1+D12*(B3-1))	=C12*(1+E12*((B3+F12)/1-1	=IF(F12=0,H12-C12,0)	=IF(F12<>0,C12-H12,0)
13	SouthAfrica	5292	3396	=D12	=E12	0	=B13*(1+D13*(B3-1))	=C13*(1+E13*((B3+F13)/1-1	=IF(F13=0,H13-C13,0)	=IF(F13<>0,C13-H13,0)
14	Russia	5147	4880	=D13	=E13	0	=B14*(1+D14*(B3-1))	=C14*(1+E14*((B3+F14)/1-1	=IF(F14=0,H14-C14,0)	=IF(F14<>0,C14-H14,0)

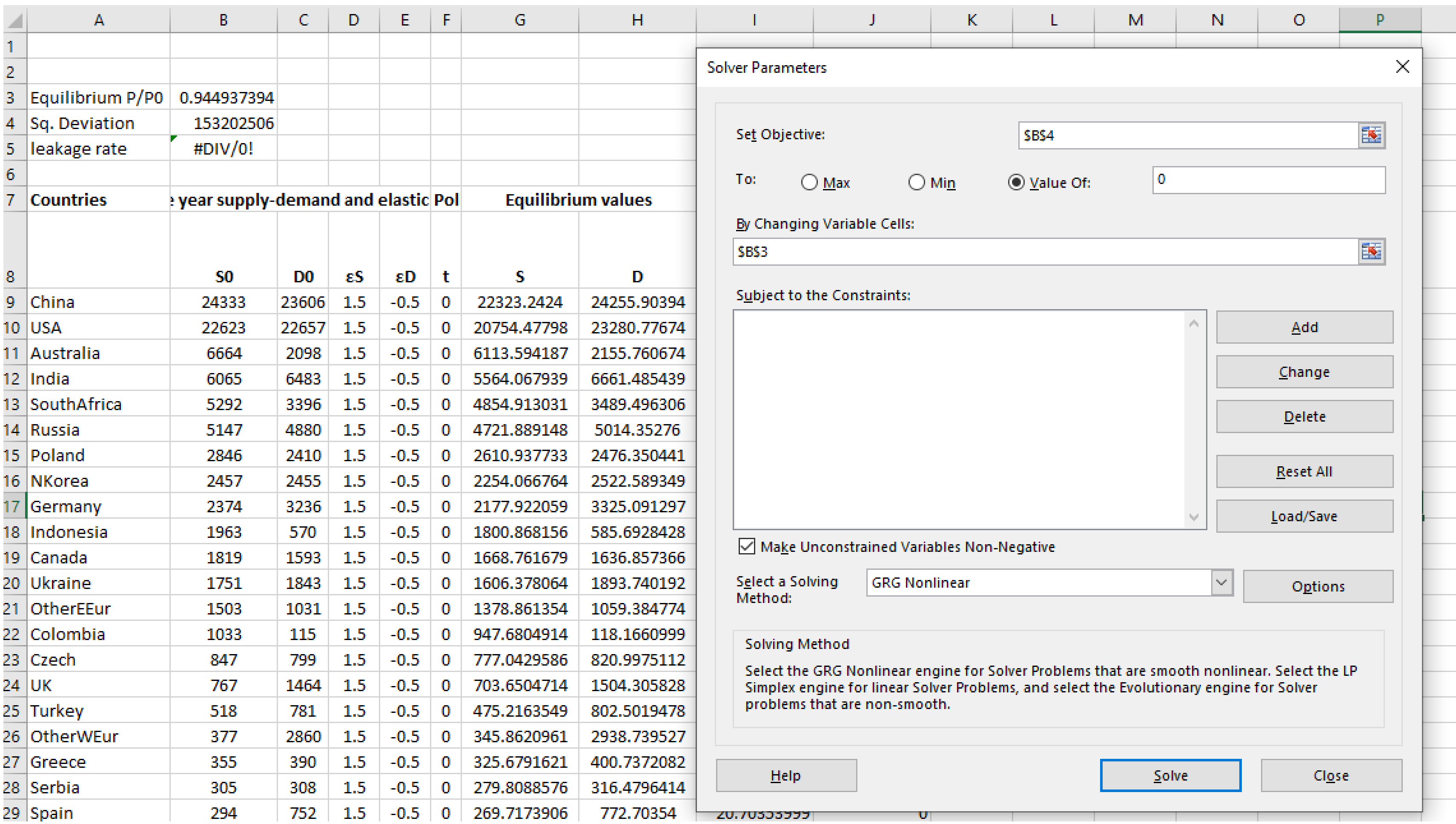
…

40	Japan	68	3543	=D39	=E39	0	=B40*(1+D40*(B3-1))	=C40*(1+E40*((B3+F40)/1-1	=IF(F40=0,H40-C40,0)	=IF(F40<>0,C40-H40,0)
41	MidEast	36	337	=D40	=E40	0	=B41*(1+D41*(B3-1))	=C41*(1+E41*((B3+F41)/1-1	=IF(F41=0,H41-C41,0)	=IF(F41<>0,C41-H41,0)
42	Philippines	27	210	=D41	=E41	0	=B42*(1+D42*(B3-1))	=C42*(1+E42*((B3+F42)/1-1	=IF(F42=0,H42-C42,0)	=IF(F42<>0,C42-H42,0)
43	Taiwan	2	1309	=D42	=E42	0	=B43*(1+D43*(B3-1))	=C43*(1+E43*((B3+F43)/1-1	=IF(F43=0,H43-C43,0)	=IF(F43<>0,C43-H43,0)
44	**Totals**	**=SUM(B9:B43)**	**=SUM(C9:C4**				**=SUM(G9:G43)**	**=SUM(H9:H43)**		
45										
46										

If the model is out of equilibrium the resulting imbalance is shown by cell B4 being non-zero

Calibrated models using MS Excel

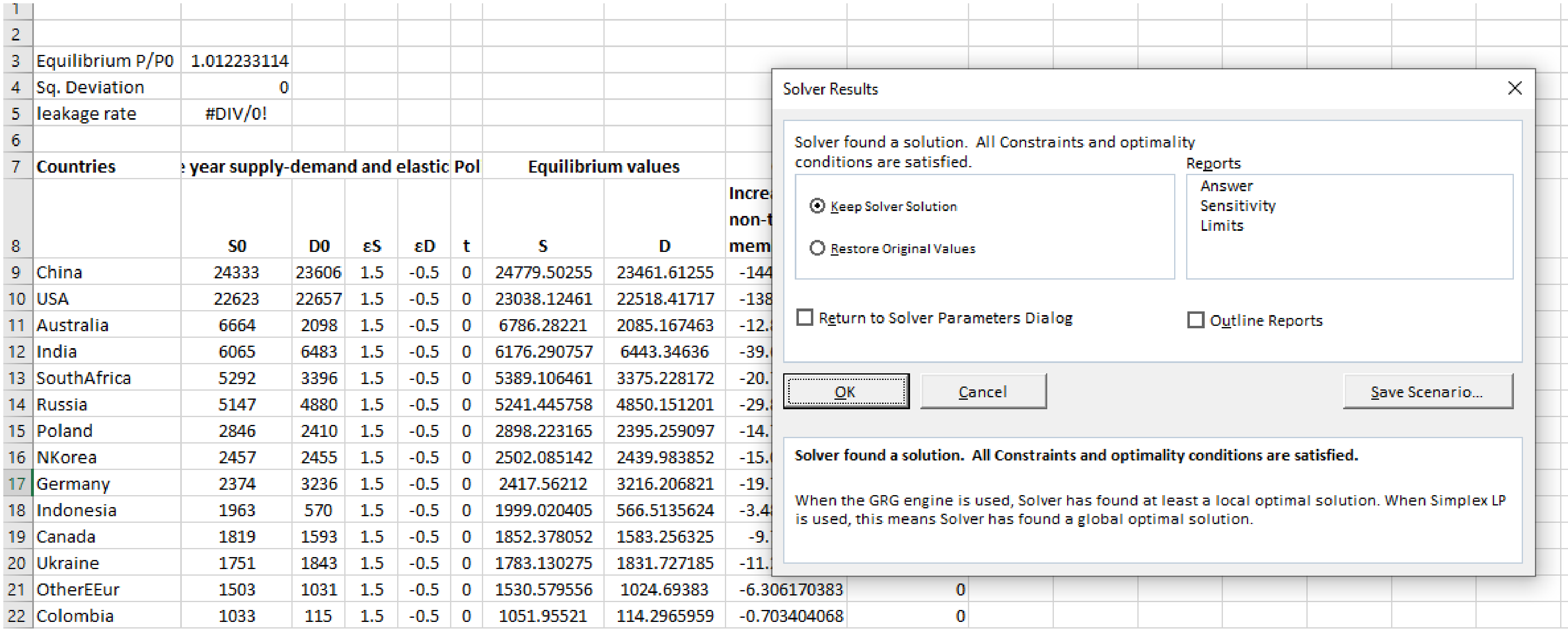
To restore balance (total supply = total demand) we use the **Excel's Solver** (Data Tab > Solver). Again you need to activate it by File > Options > Add ins



	A	B	C	D	E	F	G	H
1								
2								
3	Equilibrium P/P0	0.944937394						
4	Sq. Deviation	153202506						
5	leakage rate	#DIV/0!						
6								
7	**Countries**	**e year supply-demand and elastic**				**Pol**	**Equilibrium values**	
8		**S0**	**D0**	**εS**	**εD**	**t**	**S**	**D**
9	China	24333	23606	1.5	-0.5	0	22323.2424	24255.90394
10	USA	22623	22657	1.5	-0.5	0	20754.47798	23280.77674
11	Australia	6664	2098	1.5	-0.5	0	6113.594187	2155.760674
12	India	6065	6483	1.5	-0.5	0	5564.067939	6661.485439
13	SouthAfrica	5292	3396	1.5	-0.5	0	4854.913031	3489.496306
14	Russia	5147	4880	1.5	-0.5	0	4721.889148	5014.35276
15	Poland	2846	2410	1.5	-0.5	0	2610.937733	2476.350441
16	NKorea	2457	2455	1.5	-0.5	0	2254.066764	2522.589349
17	Germany	2374	3236	1.5	-0.5	0	2177.922059	3325.091297
18	Indonesia	1963	570	1.5	-0.5	0	1800.868156	585.6928428
19	Canada	1819	1593	1.5	-0.5	0	1668.761679	1636.857366
20	Ukraine	1751	1843	1.5	-0.5	0	1606.378064	1893.740192
21	OtherEEur	1503	1031	1.5	-0.5	0	1378.861354	1059.384774
22	Colombia	1033	115	1.5	-0.5	0	947.6804914	118.1660999
23	Czech	847	799	1.5	-0.5	0	777.0429586	820.9975112
24	UK	767	1464	1.5	-0.5	0	703.6504714	1504.305828
25	Turkey	518	781	1.5	-0.5	0	475.2163549	802.5019478
26	OtherWEur	377	2860	1.5	-0.5	0	345.8620961	2938.739527
27	Greece	355	390	1.5	-0.5	0	325.6791621	400.7372082
28	Serbia	305	308	1.5	-0.5	0	279.8088576	316.4796414
29	Spain	294	752	1.5	-0.5	0	269.7173906	772.70354

Calibrated models using MS Excel

See that after performing the optimization, the Sq. Deviation is zero (supply=demand) and the equilibrium price has changed.



3	Equilibrium P/P0	1.012233114								
4	Sq. Deviation	0								
5	leakage rate	#DIV/0!								
7	Countries	year supply-demand and elastic				Pol	Equilibrium values			
8		S0	D0	εS	εD	t	S	D	Incre non-t mem	
9	China	24333	23606	1.5	-0.5	0	24779.50255	23461.61255	-144	
10	USA	22623	22657	1.5	-0.5	0	23038.12461	22518.41717	-138	
11	Australia	6664	2098	1.5	-0.5	0	6786.28221	2085.167463	-12.	
12	India	6065	6483	1.5	-0.5	0	6176.290757	6443.34636	-39.	
13	SouthAfrica	5292	3396	1.5	-0.5	0	5389.106461	3375.228172	-20.	
14	Russia	5147	4880	1.5	-0.5	0	5241.445758	4850.151201	-29.	
15	Poland	2846	2410	1.5	-0.5	0	2898.223165	2395.259097	-14.	
16	NKorea	2457	2455	1.5	-0.5	0	2502.085142	2439.983852	-15.	
17	Germany	2374	3236	1.5	-0.5	0	2417.56212	3216.206821	-19.	
18	Indonesia	1963	570	1.5	-0.5	0	1999.020405	566.5135624	-3.4	
19	Canada	1819	1593	1.5	-0.5	0	1852.378052	1583.256325	-9.	
20	Ukraine	1751	1843	1.5	-0.5	0	1783.130275	1831.727185	-11.	
21	OtherEEur	1503	1031	1.5	-0.5	0	1530.579556	1024.69383	-6.306170383	0
22	Colombia	1033	115	1.5	-0.5	0	1051.95521	114.2965959	-0.703404068	0

Calibrated models using MS Excel

We perform a counterfactual analysis (what-if sg. happened) by assuming a benevolent "social planner" imposes a tax on heavy CO_2 emitters – USA and China

- What is the new equilibrium?
- By how much is global consumption reduced?
- What about the leaking rate (i.e. relative increase in demand in non-taxed countries)

Let's assume that t=1. We call the Solver again leading to the new equilibrium

Calibrated models using MS Excel

2										
3	Equilibrium P/P0	0.886468545								
4	Sq. Deviation	0								
5	leakage rate	13%								
6										
7	**Countries**	**year supply-demand and elastic**				**Pol**	**Equilibrium values**		**Change in demand**	
8		**S0**	**D0**	**εS**	**εD**	**t**	**S**	**D**	**Increase by non-taxed members**	**Decrease by taxed members**
9	China	24333	23606	1.5	-0.5	1	20189.15864	13143.01177	0	10462.98823
10	USA	22623	22657	1.5	-0.5	1	18770.36683	12614.64109	0	10042.35891
11	Australia	6664	2098	1.5	-0.5	0	5529.139572	2217.094497	119.0944967	0
12	India	6065	6483	1.5	-0.5	0	5032.147584	6851.012213	368.0122127	0
13	SouthAfrica	5292	3396	1.5	-0.5	0	4390.787307	3588.776411	192.7764113	0
14	Russia	5147	4880	1.5	-0.5	0	4270.480398	5157.016751	277.0167512	0

…

40	Japan	68	3543	1.5	-0.5	0	56.41979155	3744.120973	201.1209733	0
41	MidEast	36	337	1.5	-0.5	0	29.86930141	356.1300502	19.13005024	0
42	Philippines	27	210	1.5	-0.5	0	22.40197606	221.9208028	11.92080282	0
43	Taiwan	2	1309	1.5	-0.5	0	1.659405634	1383.306338	74.30633757	0
44	**Totals**	**91401**	**93651**				**75835.66717**	**75835.66717**		
45										

Calibrated models using MS Excel

- What is the new equilibrium?
  - New equilibrium price is 0.89

- By how much is global consumption reduced?
  - Global demand for coal (and alongside CO_2 emissions from coal) goes down by 19%

- What about the leaking rate (i.e. relative increase in demand in non-taxed countries)
  - The leaking rate is 13%. Countries that are not taxed benefit from the world price reduction and increase their consumption relative to the benchmark
  - Although global emissions go down, we might see an increase in local pollution especially by less developed countries that don’t spend on energy efficiency

General Equilibrium Modelling

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Economic Impacts of Renewable Energy Production in Germany

Christoph Böhringer, Florian Landis, Miguel Angel Tovar Reaños

Open Access Article

Abstract:

Over the last decade Germany has boosted renewable energy in power production by means of massive subsidies. The flip side are very high electricity prices which raise concerns that the transition cost towards a renewable energy system will be mainly borne by poor households. In this paper, we combine computable general equilibrium and microsimulation analyses to investigate the economic impacts of Germany's renewable energy promotion. We find that the regressive effects of renewable energy promotion could be attenuated by alternative subsidy financing mechanisms.

Published in Volume 38, KAPSARC Special Issue of the bi-monthly journal of the IAEE's Energy Economics Education Foundation.

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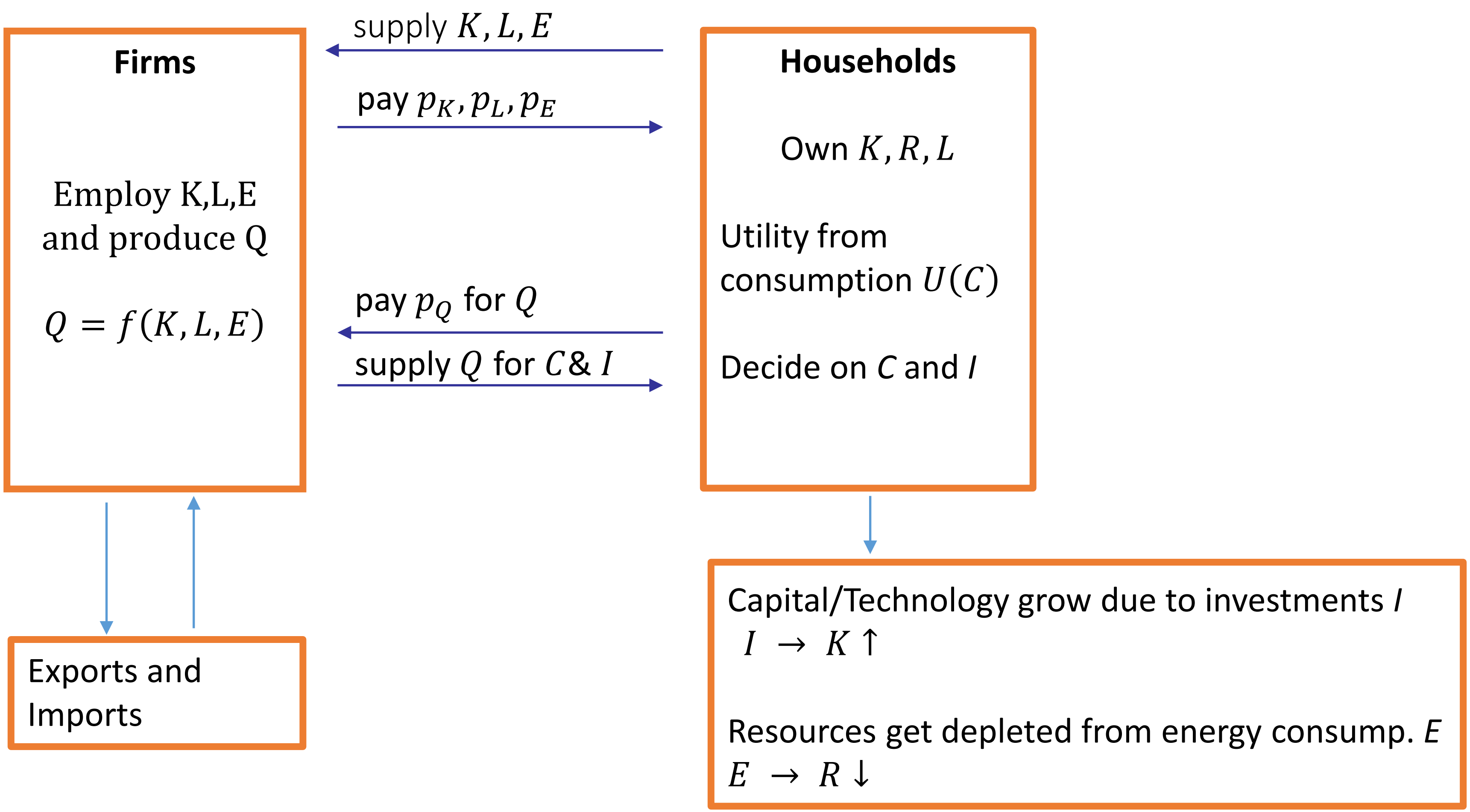
Citation Statistics

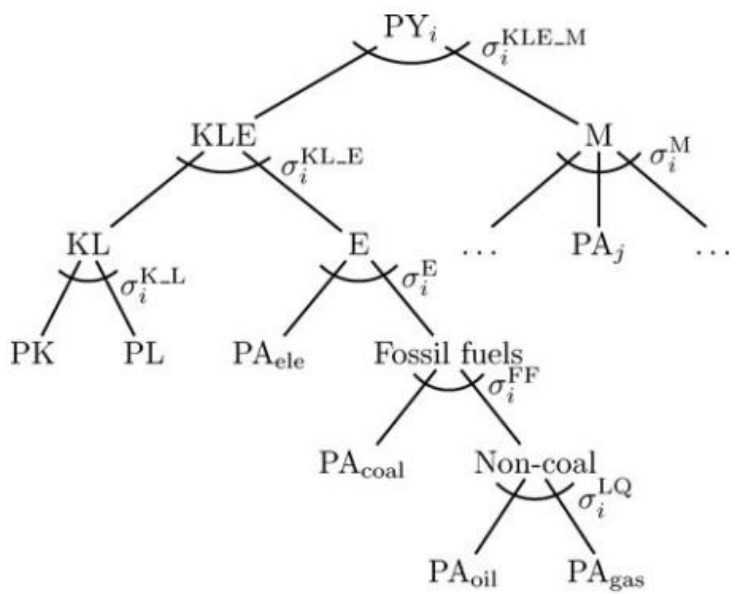
- Set up a model replicating all economic flows on the benchmark
  - Production, consumption, imports, exports, government, policy in place
- Impose policies or alter existing ones to see how the equilibrium changes
- The policy that gives the highest “social benefit” wins
- Most times an efficient policy (good for country) is not equitable (poor pay more)

General Equilibrium Modelling



General Equilibrium Modelling

Figure 1: Cost function in production



- Each node represents a production technology; σ elast. of substitution between inputs
- The exact specification depends on the modeller and on data availability
- Important data are the different elasticities of substitution σ and all economic flows
- Nowadays all countries collect data on their economic flows in Social Accounting Matrices (SAM)

General Equilibrium Modelling

			Goods and services	Production Activities	Factors		Resident Institutions			Savings-Investments	Rest of the world	Total
					Labour	*Capital Services*	*Households*	*Firms*	*Public sector*			
			(1)	(2)	(3)		(4)			(5)	(6)	
Goods and services	(1)		Trade/transp. marg.	Intermediate consumption			Final cons.hous.		Final cons.of PS	Investment & var.stocks	Exports	Demand of goods
Production Activities	(2)		Domestic production						Subsidies to production			Inflows of activities
Factors	(3)	*Labour*		Wages and Salaries							labour inc. from ROW	Labour incomes
		Capital Serv.		Earn.b.taxes (EBT)								Capital incomes
Resident Institutions	(4)	*House holds*			Wages and Salaries		Intra-hous. transfers	Distributed profits	Transfers to households		Transferts from ROW	Households incomes
		Firms				Earn.b.Taxes (EBT)					Transferts from ROW	Firms incomes
		Public sector	Taxes on goods/serv	Taxes on activities			Taxes/social security	Taxes	Transfers within PS	Budget deficit	Transferts from ROW	PS income
Savings-Investment	(5)		Decreases of stocks	Depreciation of capital			Savings of households	Savings of firms	Budget surplus		Deficit bal.of payments.	Financial resources
Rest of the world	(6)		Imports		Remun.of ext.labour		Transfers to ROW	Transfers to ROW	Transfers to ROW	Surplus bal. of payments		Outlays to ROW
Total			Supply of goods and services	Domestic production	Payments for labour	Payments for capital services	Households expenditure	Use of EBT	Public expenditure	Total investment	Payments of ROW	

One of the accounting principles of the social accounting matrix is that total receipts must equal total expenditure in each account.

General Equilibrium Modelling

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Green tax reform, endogenous innovation and the growth dividend

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ABSTRACT

We study theoretically and numerically the effects of an environmental tax reform using endogenous growth theory. In the theoretical segment, mobile labor between manufacturing and R&D activities, and elasticity of substitution between labor and energy in manufacturing lower than unity allow for a growth dividend, even if we consider pre-existing tax distortions. The scope for innovation is reduced when we consider direct financial investment in the lab, or elastic labor supply. We then apply the core theoretical model to a real growing economy and find that a boost in long-run economic growth following such a carbon policy is a possible outcome. Redistribution of additional carbon tax revenue by lowering capital taxation performs best in terms of effciency measured by aggregate welfare. In terms of equity among social segments the progressive character of lump-sum redistribution fails when we consider very high emissions reduction targets.

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General Equilibrium Modelling

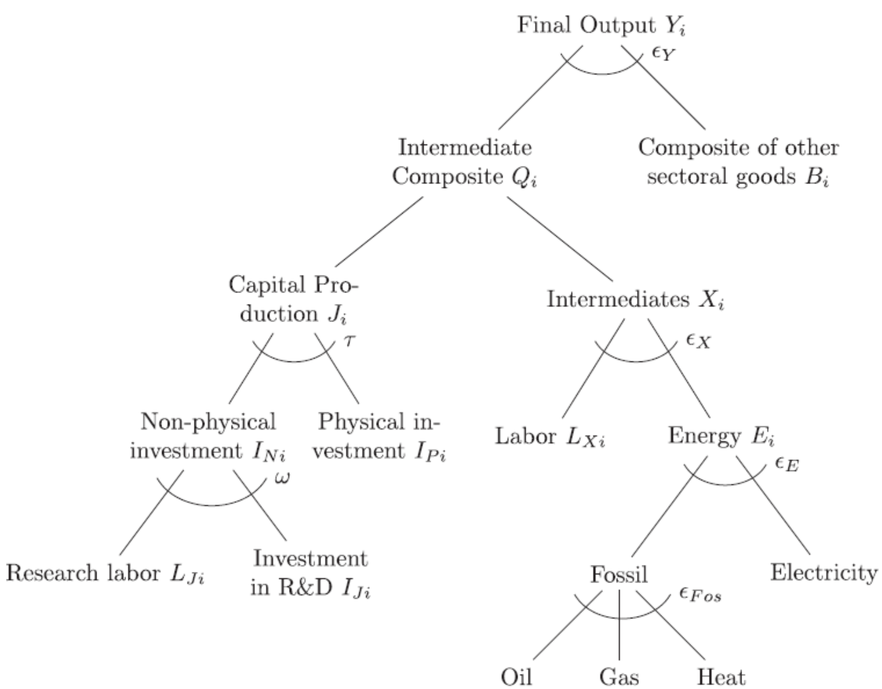
Green Tax Reform / environmental tax reform

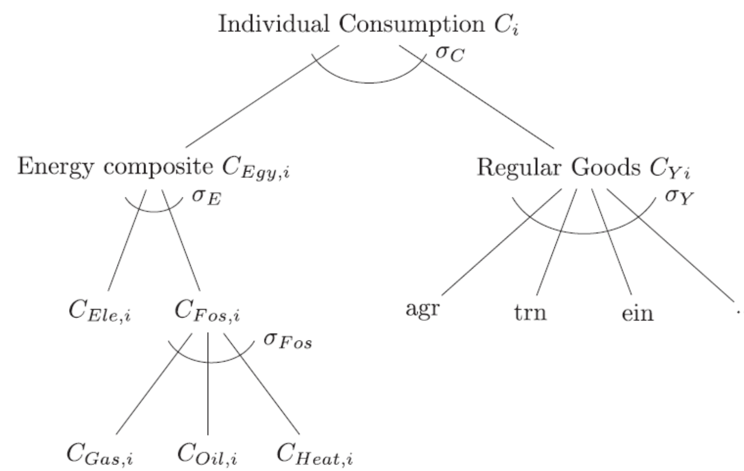
A reform in the fiscal system that raises energy/carbon taxes (good tax) and uses the revenue to reduce other distortive taxes (e.g. capital taxation) or is being redistributed per capita

- Redistributing taxes per capita (lump-sum) is better for the less well-off: the tax amount is a bigger part of their income than for the rich
- The alternative would be to use the revenue to reduce capital taxes, which of course promotes investment and the growth of the economy (capital owners)
- Higher growth is however good for the future benefit of the whole society.
- In the end it's a political and social decision which way forward

General Equilibrium Modelling

Production and consumption structure of the model



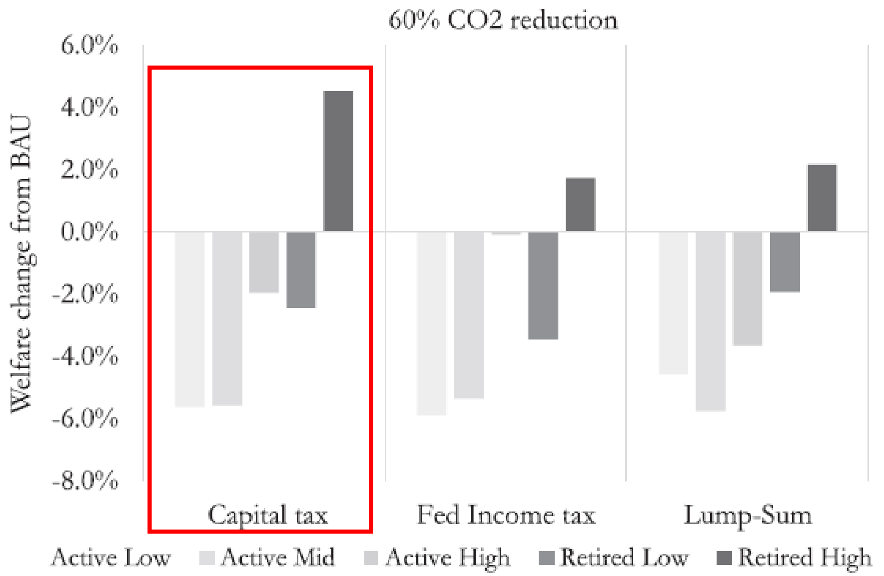


General Equilibrium Modelling

- Efficiency (good for the economy as a whole) vs. equity (rich vs. poor):
- Using carbon tax revenue to reduce capital taxes is good for the country but affects more the less well-off.

Welfare change (in % from BAU) for different CO2 emissions reduction targets – excludes the first dividend.

Target	Capital tax	Fed. Income tax	Lump-sum
20%	− 1.19%	− 1.24%	− 1.33%
40%	− 2.09%	− 2.13%	− 2.25%
60%	− 3.79%	− 3.83%	− 4.00%



5 household types: 3 active (poor, mid-income, rich) and 2 retired (poor, rich) →