Lecture 3

Applications: Automation & AI, Germany without Russian Gas

Macroeconomics EC2B1

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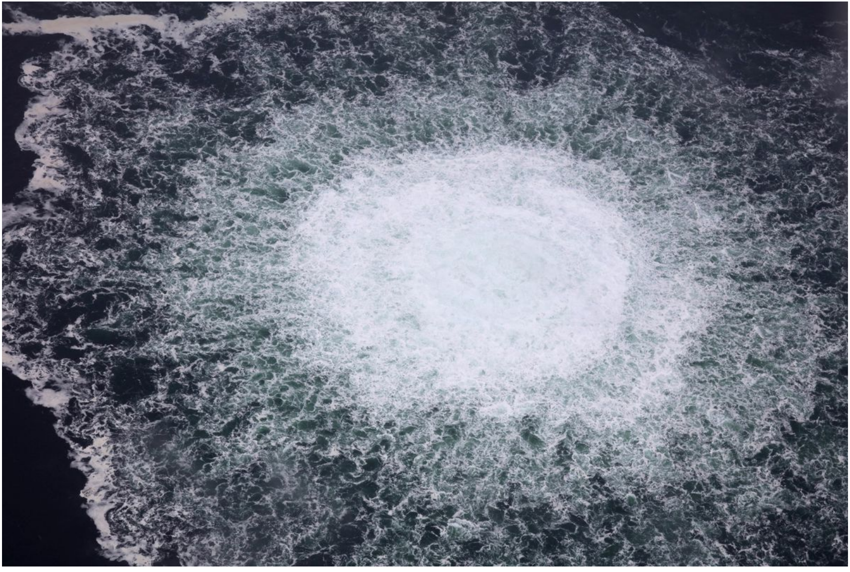
London School of Economics, Winter 2025/26

What today’s lecture is about: part 1

What today's lecture is about: part 2



Background: German primary energy consumption in 2021

	Oil	Gas	Coal	Nuclear	Renew.	Rest	Total
TWh	1077	905	606	209	545	45	3387
%	31.8	26.7	17.9	6.2	16.1	1.3	100
of which Russia	34%	55%	26%	0%	0%	0%	30%

Source: Bachmann et al. (2022a)

Plan: two topics and two corresponding models

1. Automation & AI

   - The "task-based model"

2. The Power of Substitution: Germany without Russian Gas

   - The CES production function: complementarities and substitution in production

Background readings: automation & AI (not examinable)

- Jones (2026) “A.I. and Our Economic Future”
  https://web.stanford.edu/~chadj/AIandEconomicFuture.pdf
- Aghion and Bunel (2024) “AI and Growth: Where Do We Stand?”
  https://www.frbsf.org/wp-content/uploads/AI-and-Growth-Aghion-Bunel.pdf
- Acemoglu (2024) “The Simple Macroeconomics of AI”
  https://economics.mit.edu/sites/default/files/2024-04/The%20Simple%20Macroeconomics%20of%20AI.pdf
- Andrej Karpathy podcast https://www.dwarkesh.com/p/andrej-karpathy
- Wolf (2025) “What Jobs Are Made Of” https://thomwolf.substack.com/p/what-jobs-are-made-of
- Muro, Maxim, and Whiton (2019) “Automation and Artificial Intelligence: How machines are affecting people and places” https://www.brookings.edu/wp-content/uploads/2019/01/2019.01_BrookingsMetro_Automation-AI_Report_Muro-Maxim-Whiton-FINAL-version.pdf
- Acemoglu and Autor (2011) “Skills, Tasks and Technologies: Implications for Employment and Earnings,” Handbook of Labor Economics
- Zeira (1998) “Workers, Machines & Economic Growth”
  https://josephzeira.weebly.com/uploads/5/7/3/4/57342721/98_qje.pdf

Background readings: Germany without Russian Gas (not examinable)

- "What if? The macroeconomic and distributional effects for Germany of a stop of energy imports from Russia" https://benjaminmoll.com/what_if/
- "The Power of Substitution: The Great German Gas Debate in Retrospect" https://benjaminmoll.com/GGGD/
- Marginal Revolution "Substitutes Are Everywhere" https://marginalrevolution.com/marginalrevolution/2023/05/substitutes-are-everywhere-the-great-german-gas-debate-in-retrospect.html
- Video available for Brookings presentation https://www.youtube.com/watch?v=-bs5QYr-w08&t=11295s
- Non-technical summary https://www.brookings.edu/articles/the-power-of-substitution-the-great-german-gas-debate-in-retrospect/
- Appendix E of Moll-Schularick-Zachmann "36 concrete cases of substitution and demand reduction" https://benjaminmoll.com/GGGD/

Automation & AI

Questions

1. How much will AI improve living standards?
    - Some (e.g. Acemoglu): business as usual, 0.05% higher growth
    - Others (e.g. EpochAI): $>$ 20% annual growth by 2028

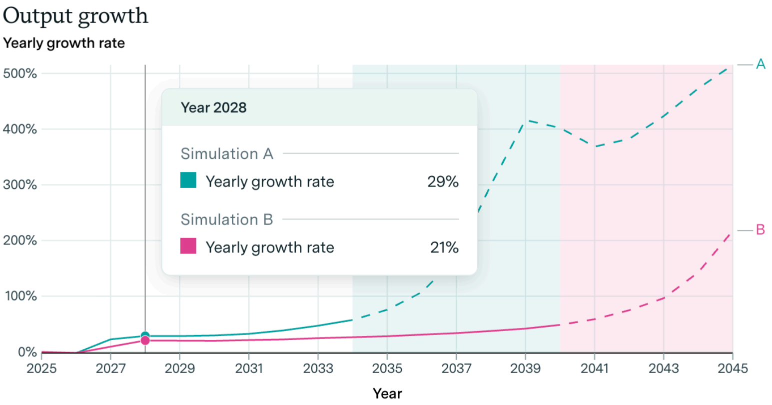
2. What are the distributional effects? On labor vs capital income? On wealth distribution?

3. ...

Goal: show you a simple framework to think about these questions

One Prediction: EpochAI https://epoch.ai/gate#econ-growth

EpochAI prediction: $>$ 20% growth rate, 3 years from now!



Gross World Product (GWP) growth rates over years of simulation. Growth increases approximately tenfold from current levels well before full automation. Show more.

A simple framework to think about automation & AI

- Starting point: standard producer theory
- Standard case: output Y is produced using capital K and labor L

$$Y = F(K, L)$$

- Useful background readings: Your EC1A1 notes on producer theory
- This lecture: somewhat deeper theory of the production process
  - "Task-based model"
  - Key insight: machines substitute for tasks, not jobs
  - Simplified version of Zeira (1998) "Workers, Machines & Economic Growth"

Some production functions you should already know

Technology: output $Y = F(K, L)$ is produced using capital K and labor L

1. Cobb-Douglas

$$Y = AK^{\alpha}L^{1-\alpha}, \quad A > 0,\ 0 < \alpha < 1$$

2. Perfect substitutes

$$Y = A_K K + A_L L, \quad A_K, A_L > 0$$

3. Perfect complements, fixed proportions, or "Leontief"

$$Y = \min\{B_K K, B_L L\}, \quad B_K, B_L > 0$$

Reminder: useful property of the Cobb-Douglas function

- Useful property: factor shares equal the coefficients
- In particular
$$Y = AK^{\alpha}L^{1-\alpha}$$
implies
$$\text{capital share} = \frac{RK}{Y} = \alpha, \qquad \text{labor share} = \frac{wL}{Y} = 1 - \alpha$$
where R and w are the prices of capital and labor (rental rate and wage)
- Derivation: FOCs of
$$\max_{K,L} \; AK^{\alpha}L^{1-\alpha} - RK - wL$$

The "Task-Based Model": Key Ideas and Insights

- Go one level deeper than $Y = F(K, L)$
- Think of production/jobs as requiring completion of a list of tasks
  - Example: HR manager, tasks = screen CVs, interview applicants,...
- Tasks can be completed by either humans (L) or machines (K)
  - Automation: over time, more and more tasks can be done by K
- Key insight: machines substitute for tasks, not jobs
- Key result: will write prod. function in terms of tasks (rather than K & L)
- ... but will end up with something that looks like Cobb-Douglas prod. fn

$$Y = AK^{\alpha}L^{1-\alpha}$$

where α has interesting interpretation:

$$\alpha = \text{share of automated tasks}$$

A Simple Task-Based Model: Technology

Production combines different tasks $i = 1, ..., N$

$$Y = \tilde{A} X_1^{1/N} X_2^{1/N} \cdot ... \cdot X_N^{1/N}$$

where X_i = "task services". Note: natural generalization of $Y = \tilde{A} X_1^{1/2} X_2^{1/2}$.

Tasks are either "automatable" (= can be produced using K or L) or not

- notation: K_i, L_i = capital/labor used in task i
- if task i is automatable, K_i and L_i are perfect substitutes for producing it

$$X_i = \begin{cases} L_i & \text{if not automatable} \\ L_i + K_i & \text{if automatable} \end{cases}$$

Note: machines substitute for tasks, not jobs

All Primitives of the Economy

- **Preferences:** Utility from consumption of final good C (no labor supply)

$$U(C)$$

- **Technology:**

$$Y = \tilde{A} X_1^{1/N} X_2^{1/N} \cdot \ldots \cdot X_N^{1/N}, \qquad X_i = \begin{cases} L_i & \text{if not automatable} \\ L_i + K_i & \text{if automatable} \end{cases}$$

- **Resource constraint:**

$$\sum_{i=1}^{N} K_i = K, \qquad \sum_{i=1}^{N} L_i = L, \qquad C = Y$$

where K, L = economy's total endowments of capital/labor

- Welfare theorems hold $\Rightarrow$ solve for CE by finding PE allocation

A Simple Task-Based Model

Assumption: labor L is sufficiently scarce that it's optimal to automate all automatable tasks (in CE, scarce $L \Rightarrow w > R \Rightarrow$ automate when possible)

$$X_i = \begin{cases} L_i & \text{if not automatable} \\ K_i & \text{if automatable} \end{cases}$$

Notation:

- n = number of automatable tasks
- $\alpha = n/N$ = share of automatable tasks

Result: everything symmetric $\Rightarrow$ allocate labor and capital evenly $\Rightarrow$

$$X_i = \begin{cases} L/(N-n) & \text{if not automatable} \\ K/n & \text{if automatable} \end{cases}$$

Derivation: $K_i = \bar{K}$ for n tasks, $L_i = \bar{L}$ for $N-n$ tasks. Resource constraints:

$$(N-n)\times 0 + n\bar{K} = K, \quad (N-n)\times \bar{L} + n \times 0 = K \quad \Rightarrow K_i = \frac{K}{n} \quad \text{and} \quad L_i = \frac{L}{N-n}$$

A Simple Task-Based Model

Plugging

$$X_i = \begin{cases} L/(N-n) & \text{if not automatable} \\ K/n & \text{if automatable} \end{cases}$$

into $Y = \tilde{A} X_1^{1/N} X_2^{1/N} \cdot \ldots \cdot X_N^{1/N}$ yields

$$\begin{aligned} \Rightarrow \quad Y &= \tilde{A} \left(\frac{K}{n}\right)^{n/N} \left(\frac{L}{N-n}\right)^{(N-n)/N} \\ &= \tilde{A} \left(\frac{1}{N}\frac{K}{n/N}\right)^{n/N} \left(\frac{1}{N}\frac{L}{(N-n)/N}\right)^{(N-n)/N} \\ &= (\tilde{A}/N) \left(\frac{K}{\alpha}\right)^{\alpha} \left(\frac{L}{1-\alpha}\right)^{1-\alpha} \\ &= AK^{\alpha}L^{1-\alpha} \quad \text{where} \quad A = \frac{\tilde{A}/N}{\alpha^{\alpha}(1-\alpha)^{1-\alpha}}, \quad \alpha = n/N \end{aligned}$$

A Simple Task-Based Model: Summary

- Started with $Y = \tilde{A} X_1^{1/N} X_2^{1/N} \cdot \ldots \cdot X_N^{1/N}$ and

$$X_i = \begin{cases} L_i & \text{if not automatable} \\ L_i + K_i & \text{if automatable} \end{cases}$$

- End up with

$$Y = AK^{\alpha} L^{1-\alpha} \quad \alpha = \text{share of automated tasks}$$

- Simply a Cobb-Douglas production function with capital share = share of automated tasks!

- Automation = increase in α!

Implications: Aggregate Effects of Automation

- Question: what happens to output Y when there is automation $\alpha \uparrow$?
- Intuitively: $\partial Y / \partial \alpha > 0$ bc production possibility frontier expands as $\alpha \uparrow$
- Task-based model yields

$$Y = AK^{\alpha} L^{1-\alpha} \quad \text{with} \quad A = \frac{\tilde{A}/N}{\alpha^{\alpha}(1-\alpha)^{1-\alpha}} \qquad (*)$$

- Claim: this indeed implies $\partial Y / \partial \alpha > 0$. Next: show this.
- Recall assumption: labor L is sufficiently scarce that it's optimal to automate all automatable tasks. Turns out: condition for this is

$$\frac{L}{K} < \frac{1-\alpha}{\alpha} \quad \text{(Note: in CE, ass'n} \Rightarrow w > R\text{)}$$

- Claim: $\partial Y / \partial \alpha > 0$ under this same condition. Proof: differentiate $(*)$

$$\frac{\partial \log Y}{\partial \alpha} = \log K - \log L - \log \alpha + \log(1-\alpha) = \log\left(\frac{(1-\alpha)K}{\alpha L}\right) > 0$$

Implications: Distributional Effects of Automation

Payments to labor and capital

$$wL = (1-\alpha)Y, \qquad RK = \alpha Y$$

When $\alpha \uparrow$ what happens to capital income RK?

- it increases unambigously

When $\alpha \uparrow$ what happens to labor income wL? Two offsetting effects:

1. Displacement effect: $wL = (1-\alpha)Y$
2. Productivity effect: $wL = (1-\alpha)Y$
    - Logic: What technology doesn't replace it complements!

Growth effects? > 20% growth rates 3 years from now?

Here: some projections using task-based model from Jones & Tonetti (2026) "Past Automation & Future AI: How Weak Links Tame the Growth Explosion"

Figure 10: Simulating the Future: Economic Growth

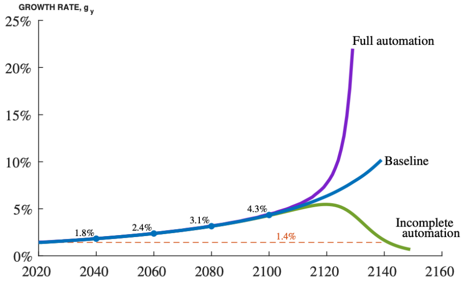
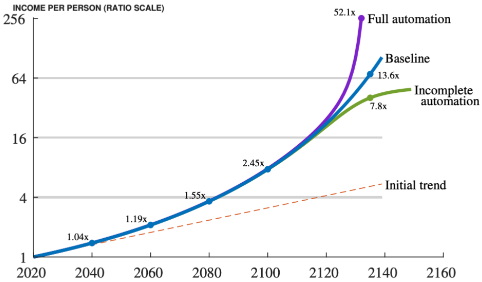
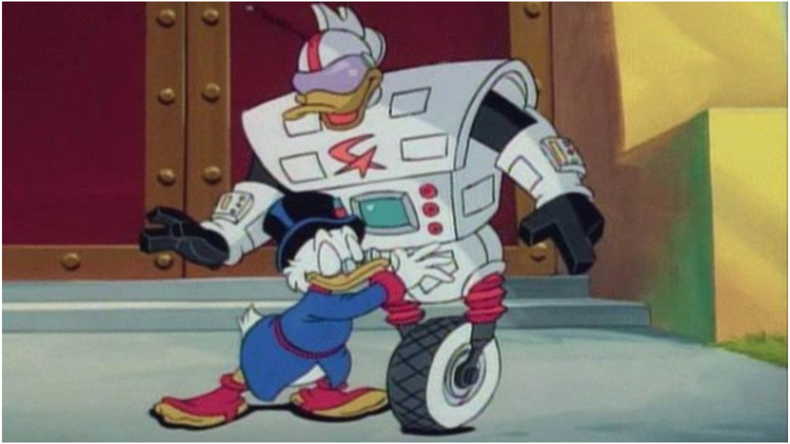


Figure 11: Simulating the Future: GDP per Person



AI benefits owners of AI capital



See “Uneven Growth: Automation’s Impact on Income and Wealth Inequality”

https://benjaminmoll.com/UG/

The Worrisome Scenario: Nobel Laureate James Meade writing in 1964 (!) https://benjaminmoll.com/meade/

- "But what of the future? Suppose that automation should drastically reduce [the labor share ...]. There would be a limited number of exceedingly wealthy property owners;"
- "the proportion of the working population required to man the extremely profitable automated industries would be small; wage-rates would thus be depressed;"
- "there would have to be a large expansion of the production of the labour-intensive goods and services which were in high demand by the few multi-multi-multi-millionaires;"
- "we would be back in a super-world of an immiserised proletariat and of butlers, footmen, kitchen maids, and other hangers-on. "

Limitations of the Task-Based Model

- A great starting point to think about automation and AI
- But: a job is more than just executing a list of tasks
- I like Wolf blog post who calls this “judgement” and “agency”, also see Ryo Lu’s “taste, vision, judgment, context”
  https://thomwolf.substack.com/p/what-jobs-are-made-of
- What else?

The Power of Substitution
Germany without Russian Gas

Embargo debate after Russian invasion of Ukraine

manager magazin

Money for Russian gas imports

660 million euros a day – this is how we finance Putin's war

Gas from Russia: For President Putin, gas exports are currently the most important source of foreign exchange Photo: Dmitry Lovetsky / dpa

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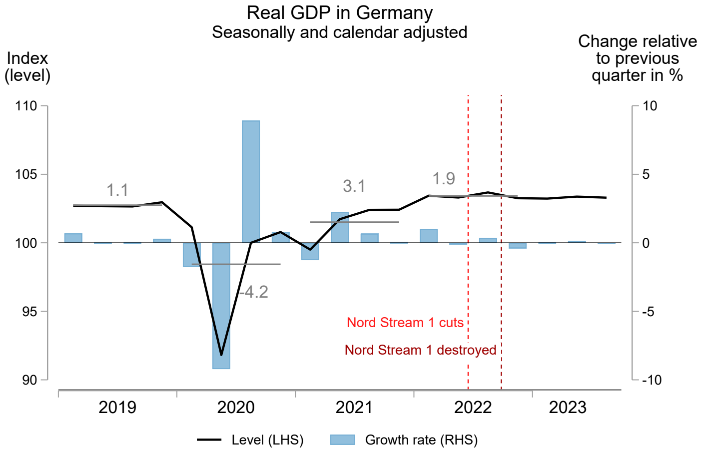
Putin is swimming in our money

embargo debate

BASF boss warns of destruction of the "entire economy"

Oil and gas are central to the chemical industry. Should their imports from Russia be stopped, BASF boss Martin Brudermüller predicts the "worst crisis since the end of the Second World War".

Destruction of economy? Worst crisis since end of WWII?



Instead: a mini recession followed by stagnation

The CES production function:

Complementarities and substitution in production

Plan and useful background readings

Introduce a very useful production function: the "constant elasticity of substitution (CES) production function"

- this lecture's main application: substitution of natural gas in production
- but to underline generality: introduce with capital and labor $Y = F(K, N)$
- many other applications
- example: skill-biased technical change & skill premium $Y = F(N_s, N_u)$
- another possibility: CES utility function $\Rightarrow$ substitution in consumption

Useful background readings

- Your EC1A1 lecture notes on producer theory
- Chapter 2 here
  https://web2.econ.ku.dk/okocg/MAT-OEK/Mak%C3%98k2/Mak%C3%98k2-2015/Forel%C3%A6sninger/Ch1-3-M2-2015-3.pdf
- Appendix A.2 here https://benjaminmoll.com/RussianGas_Appendix/

Some production functions you should already know

Technology: output $Y = F(K, N)$ is produced using capital K and labor N

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$$Y = AK^{\alpha}N^{1-\alpha}, \quad A > 0,\ 0 < \alpha < 1$$

2. Perfect substitutes

$$Y = A_K K + A_N N, \quad A_K, A_N > 0$$

3. Perfect complements, fixed proportions, or "Leontief"

$$Y = \min\{B_K K, B_N N\}, \quad B_K, B_N > 0$$

The CES Production Function

$$Y = F(K, N) = \left(\alpha^{\frac{1}{\sigma}}(A_K K)^{\frac{\sigma-1}{\sigma}} + (1-\alpha)^{\frac{1}{\sigma}}(A_N N)^{\frac{\sigma-1}{\sigma}}\right)^{\frac{\sigma}{\sigma-1}}$$

- The CES production function is a generalization of the three production functions on previous slide
- Key parameters
  - σ: elasticity of substitution, here between K and N
  - α: share parameter
  - A_K, A_N: capital- and labor productivity (factor-specific productivity)
- Will often see it written slightly differently, e.g.

$$Y = (\theta_K (A_K K)^\rho + \theta_N (A_N N)^\rho)^{1/\rho}$$

that's the same thing, e.g. $\sigma = 1/(1-\rho)$

Special cases of the CES production function

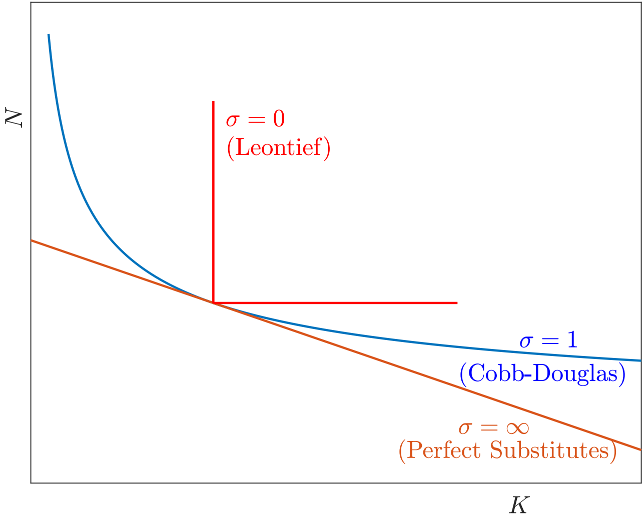
$$Y = \left(\alpha^{\frac{1}{\sigma}}(A_K K)^{\frac{\sigma-1}{\sigma}} + (1-\alpha)^{\frac{1}{\sigma}}(A_N N)^{\frac{\sigma-1}{\sigma}}\right)^{\frac{\sigma}{\sigma-1}}, \quad \sigma = \text{elasticity of substitution}$$

1. Case $\sigma = 1$: Cobb-Douglas
$$Y = \left(\frac{A_K K}{\alpha}\right)^{\alpha}\left(\frac{A_N N}{1-\alpha}\right)^{1-\alpha} = AK^{\alpha}N^{1-\alpha}$$
2. Case $\sigma \to \infty$: perfect substitutes
$$Y = A_K K + A_N N$$
3. Case $\sigma = 0$: perfect complements, fixed proportions, or "Leontief"
$$Y = \min\left\{\frac{A_K K}{\alpha}, \frac{A_N N}{1-\alpha}\right\}$$

Derivations (see supplement)

- proof of case 2 relatively simple: as $\sigma \to \infty$, $\frac{1}{\sigma} \to 0$, $\frac{\sigma-1}{\sigma} \to 1$, $\frac{\sigma}{\sigma-1} \to 1$
- proof of cases 1 and 3: more complicated, need to apply l'Hopital's rule

Isoquants of the CES production function



CES production function: marginal products and MRT

$$Y = \left(\alpha^{\frac{1}{\sigma}}(A_K K)^{\frac{\sigma-1}{\sigma}} + (1-\alpha)^{\frac{1}{\sigma}}(A_N N)^{\frac{\sigma-1}{\sigma}}\right)^{\frac{\sigma}{\sigma-1}}$$

- Marginal product of capital

$$\frac{\partial F(K,N)}{\partial K} = \left(\alpha^{\frac{1}{\sigma}}(A_K K)^{\frac{\sigma-1}{\sigma}} + (1-\alpha)^{\frac{1}{\sigma}}(A_N N)^{\frac{\sigma-1}{\sigma}}\right)^{\frac{\sigma}{\sigma-1}-1} \alpha^{\frac{1}{\sigma}} A_K^{\frac{\sigma-1}{\sigma}} K^{-\frac{1}{\sigma}}$$

- Marginal product of labor

$$\frac{\partial F(K,N)}{\partial N} = \left(\alpha^{\frac{1}{\sigma}}(A_K K)^{\frac{\sigma-1}{\sigma}} + (1-\alpha)^{\frac{1}{\sigma}}(A_N N)^{\frac{\sigma-1}{\sigma}}\right)^{\frac{\sigma}{\sigma-1}-1} (1-\alpha)^{\frac{1}{\sigma}} A_N^{\frac{\sigma-1}{\sigma}} N^{-\frac{1}{\sigma}}$$

- Marginal rate of transformation

$$\Rightarrow \frac{\partial F(K,N)/\partial K}{\partial F(K,N)/\partial N} = \left(\frac{\alpha}{1-\alpha}\right)^{1/\sigma} \left(\frac{A_K}{A_N}\right)^{\frac{\sigma-1}{\sigma}} \left(\frac{K}{N}\right)^{-1/\sigma}$$

Elasticity of substitution: how input mix responds to prices

- Consider profit maximizing firm: $\max_{K,N} \; F(K,N) - WN - RK$ where R and W = prices of capital and labor. Optimality:

$$\frac{\partial F(K,N)}{\partial K} = R, \qquad \frac{\partial F(K,N)}{\partial N} = W \quad \Rightarrow \quad \frac{\partial F(K,N)/\partial K}{\partial F(K,N)/\partial N} = \frac{R}{W}$$

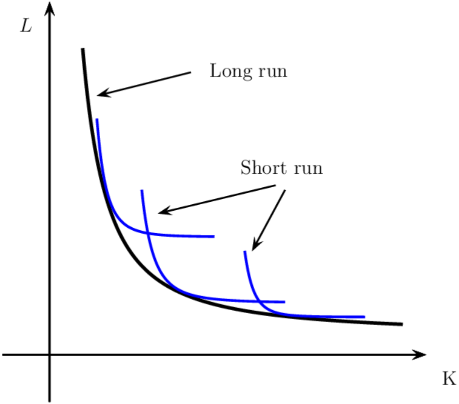
- Using expression from previous slide

$$\left(\frac{\alpha}{1-\alpha}\right)^{1/\sigma}\left(\frac{A_K}{A_N}\right)^{\frac{\sigma-1}{\sigma}}\left(\frac{K}{N}\right)^{-1/\sigma} = \frac{R}{W} \quad \Rightarrow \quad \frac{K}{N} = \text{constant} \times \left(\frac{R}{W}\right)^{-\sigma}$$

- Response of input mix K/N to factor prices R/W depends on σ
  - Leontief $\sigma = 0$: input mix does not respond to prices at all
  - Perfect substitutes $\sigma \to \infty$: input mix responds extremely strongly
  - In general

$$\frac{d\log(K/N)}{d\log(R/W)} = -\sigma$$

Le Chatelier principle: long run elasticity > short run elasticity



The LeChatelier Principle

By PAUL MILGROM AND JOHN ROBERTS*

The LeChatelier principle, in the form introduced into economics by Paul A. Samuelson, asserts that at a point of long-run equilibrium, the derivative of long-run compensated demand with respect to own price is larger in magnitude than the derivative of short-run compensated demand. We introduce an extended LeChatelier principle that applies also to large price changes and to uncompensated demand as well as to a wide range of concave and nonconcave maximization problems outside the scope of demand theory. This extension also clarifies the intuitive basis of the principle. (*JEL* C60, D10, D20).

The idea that long-run demand is typically more elastic than short-run demand is common in economics. The LeChatelier principle expresses this idea mathematically. The principle has its cleanest expression in the neoclassical theory of the firm, where it applies to input demand. Let there be two inputs, say capital and labor, and suppose that the price of labor falls. In the short run, if the capital input is fixed, the direct effect of the change will be to lead to (weakly) more labor being employed. In the long run, changes in capital usage may occur which alter the productivity of labor. The first formal analysis to conclude that such changes would *increase* the use of labor was offered by Paul A. Samuelson (1947), who returned to the subject frequently (Samuelson 1949, 1960a, 1960b, 1972). His original treat-

Various intuitive arguments have been offered to explain why labor demand should become (weakly) more elastic when capital is adjusted, the most accurate of which goes as follows. First suppose capital and labor are substitutes in the sense that increasing the use of one reduces the marginal product of the other. (This implies that the two are also substitutes in the demand-theoretic sense that lowering the price of one decreases the demand for the other.) Then in the long run the firm will reduce its use of capital in response to the lower price of labor. Because the inputs are substitutes, reducing the amount of capital raises the marginal product of labor, and this results in a further increase in labor's employment. Thus, the long-run adjustment is greater than the short-run one. On the other hand, if

Micro vs macro elasticities

- **Micro:** substitution within a given production process
    - often limited, production close to Leontief
- **Macro:** substitution not just within production processes / firms but also across production processes / firms (extensive margin)
    - often substantial, especially with time (le Chatelier)
- In general: macro elasticity $>$ micro elasticity

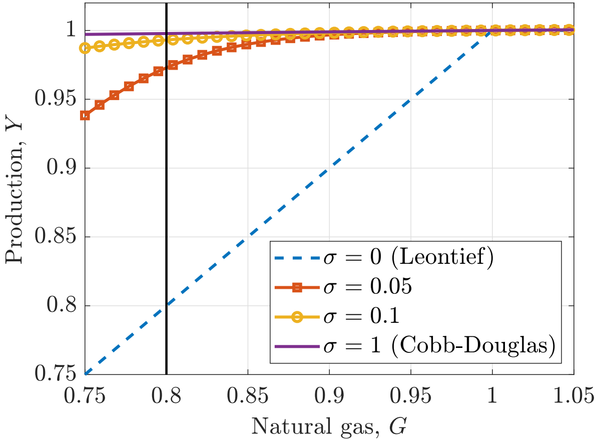
Application to gas crisis: how much does production fall when a critical input falls?

$$Y = \left[\alpha^{\frac{1}{\sigma}} G^{\frac{\sigma-1}{\sigma}} + (1-\alpha)^{\frac{1}{\sigma}} X^{\frac{\sigma-1}{\sigma}}\right]^{\frac{\sigma}{\sigma-1}}$$

where G = gas, X = other factors, e.g. $X = \tilde{F}(K, N)$

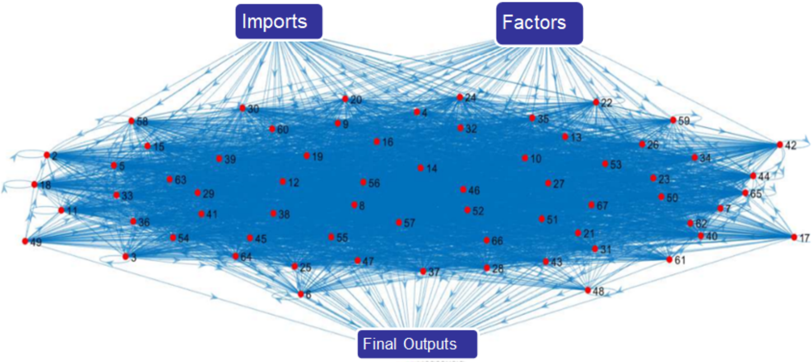
- Consider drop in G, e.g. $\Delta \log G = -20\%$. How much does Y fall?
- Gas has small expenditure share α but also small elasticity σ
- Useful benchmarks:
  1. Cobb-Douglas $\sigma = 1$: $Y = G^{\alpha} X^{1-\alpha}$ with $\alpha = 0.01$
     $$\Delta \log Y = \alpha \Delta \log G = 0.01 \times (-20\%) = -0.2\%$$
  2. Leontief $\sigma = 0$: $Y = \min\{G/\alpha, X/(1-\alpha)\}$
     $$\Delta \log Y = \Delta \log G = -20\% = \text{catastrophe}$$

Output losses for different elasticities of substitution



- Leontief $\sigma = 0$ $\Rightarrow$ production drops one-for-one with gas usage = 20%
- Even with $\sigma = 0.05$, output losses much smaller = 2.7% (almost 10x)

The worry: “cascading effects” along supply chain



- Literature on production networks, beyond scope of this course
- But same key prediction: Leontief $\Rightarrow$ total production drops one-for-one with gas usage

Back to February 2022

What things looked like in February 2022

	Oil	Gas	Coal	Nuclear	Renew.	Rest	Total
TWh	1077	905	606	209	545	45	3387
%	31.8	26.7	17.9	6.2	16.1	1.3	100
of which Russia	34%	55%	26%	0%	0%	0%	30%

Oil and coal have **global market** (+ a strategic reserve)

Gas trickier due to pipeline network, limited LNG supplies $\Rightarrow$ focus on gas

Consumption of gas (also = imports): $\approx$ 1% of GNE

- small number but energy = critical input $\Rightarrow$ amplification important

Objectives and results of March 2022 “what if?” paper

Assess consequences for Germany of cut-off from Russian energy imports

- either embargo by Germany/EU
- or stop of deliveries by Russia

Get sense of rough magnitudes of losses relative to “do nothing” baseline

1. Small GDP decline, say 0.5-1%, perhaps not even a recession?
2. Like Covid = 4.5% decline in German GDP?
3. Like Spain or Portugal during Euro crisis (5.1% & 7%)?
4. “Mass unemployment and poverty” so perhaps like Great Depression?

Our answer at the time: GDP decline up to 3% (“substantial but manageable”)

- Key mechanism: substitution of gas and gas-intensive inputs
- Based on model calculations of type we just discussed + relevant empirical estimates (e.g. of elasticities of substitutions)

Simplest Model

$$Y = \left[\alpha^{\frac{1}{\sigma}} Gas^{\frac{\sigma-1}{\sigma}} + (1-\alpha)^{\frac{1}{\sigma}} F(K,L)^{\frac{\sigma-1}{\sigma}}\right]^{\frac{\sigma}{\sigma-1}}$$

- Gas has small expenditure share, but substitution elasticity might be small
- Empirical estimates: short run ($<$12 months) demand elasticities 0.4 (Industry) and 0.2 (households)
- We assumed an elasticity of 0.1 and a -30% gas shock
- Also simulations with richer, more complicated model (Baqaee-Farhi)
  - production networks, supply chains, cascading effects
  - international trade

Table with main results of March 2022 “what if?” paper

	Baqaee-Farhi suff. statistic	Baqaee-Farhi simulation	Simplest model 10% energy $\downarrow$	Simplest model 30% gas $\downarrow$
GNE Loss, in %	< 1	< 0.3	1.5	2.3
As % of GDP	< 1	< 0.3	1.3	2.2
Per capita	€400	€100	€600	€900

- All models use conservative elasticity estimates
- Simplest model (= production fn) abstracts from trade
- The cost statements are in terms of GNE
- Some mechanisms left out $\Rightarrow$ round up headline to 3% (“safety margin”)

Reception by German government

Chancellor Scholz on TV, responding to “economists don’t predict doom”

- “But they get it wrong! And it’s honestly irresponsible to calculate around with some mathematical models that then don’t really work.”
- “I don’t know absolutely anyone in business who doesn’t know for sure that these would be the consequences.”

Head of chancellery Wolfgang Schmidt during televised panel

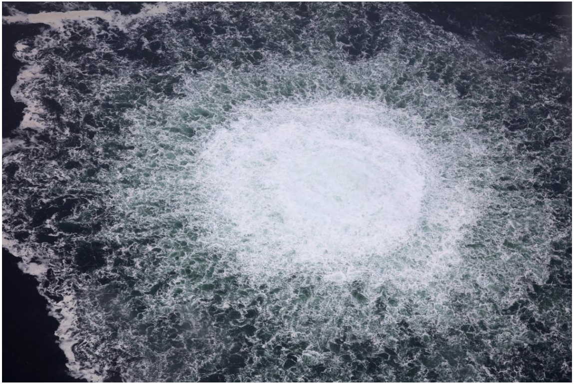
- “The second thing is, what they call elasticity, the question whether you can substitute or whether you cannot substitute gas, oil, and coal.”
- “And they always said in that model: ‘Yeah there is elasticity, it is not zero.’ But that is not true.”

Transcripts: `https://benjaminmoll.com/Scholz/` and `https://benjaminmoll.com/Schmidt/`

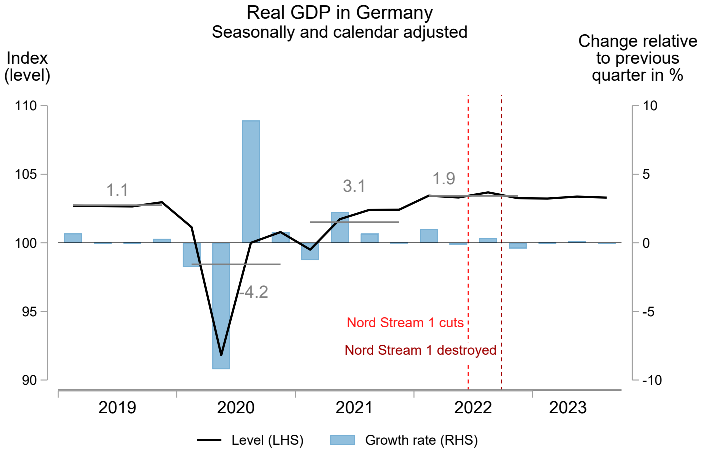
What happened next?

Soon after: **Cut-off happens** because Russia weaponizes gas supplies

- June 2022: drastically cuts supplies, particularly via Nord Stream
- August 2022: completely halt Nord Stream flows (destroyed 4 weeks later)



Destruction of economy? Worst crisis since end of WWII?



Instead: a mini recession followed by stagnation

Large adjustments on both demand- and supply side

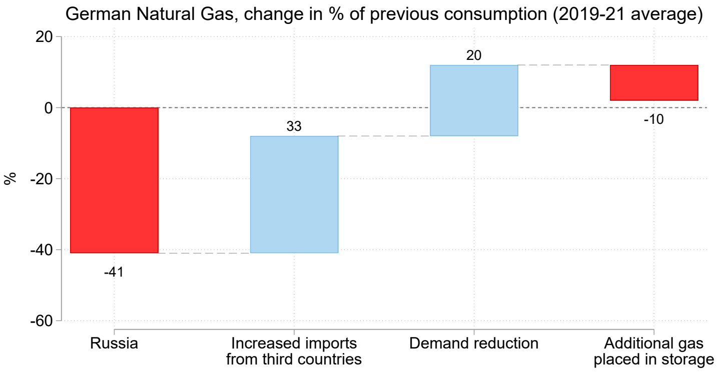


Figure 4: Germany's changing gas balance

Notes: The figure compares German natural gas imports, consumption, and storage change for the period July 2022 - March 2023, to the corresponding average from 2019 to 2021 using data from Eurostat (database code nrg_ti_gasm), McWilliams and Zachmann (2023), and AGSI. On the supply side, we take into account not only direct imports to Germany but also indirect imports via third countries as well as re-exports within Europe. More details, including on sources, are in appendix B.

Large demand reduction by industry and households

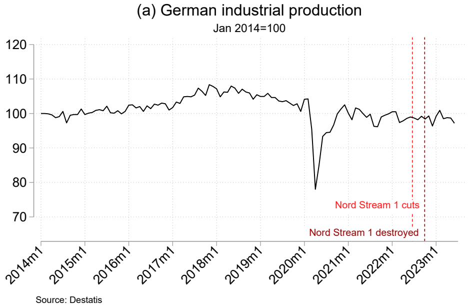
	2022/23 consumption	Baseline consumption	Reduction rel. to baseline	Percentage reduction	Bachmann et al. (August 2022)
Total	642 TWh	799 TWh	157 TWh	20%	25%
Industry	276 TWh	373 TWh	98 TWh	26%	26%
Households	281 TWh	339 TWh	58 TWh	17%	16%
Power	85 TWh	87 TWh	1 TWh	2%	45%

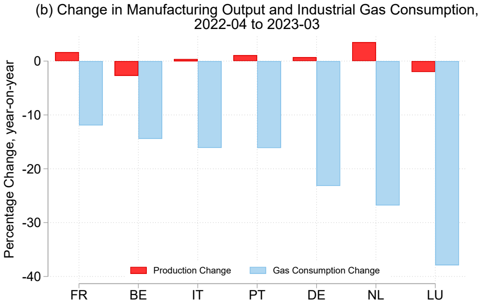
Table 2: Large demand reduction by industry and households

Notes: The table summarizes gas consumption over the period July 2022 to March 2023 ("2022/23 consumption") and compares it to average consumption in the same months in the years 2019 to 2021 ("baseline consumption").

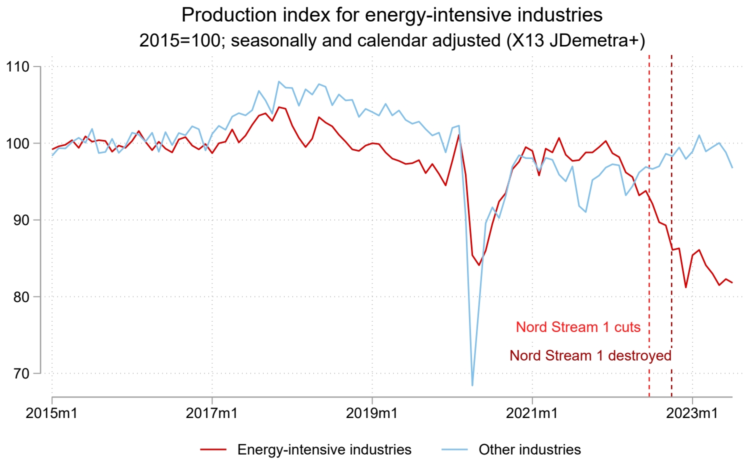
Industrial production in Germany and Europe looks nothing like Leontief

Recall: Leontief $\Rightarrow$ should have seen 20-30% drop in industrial production



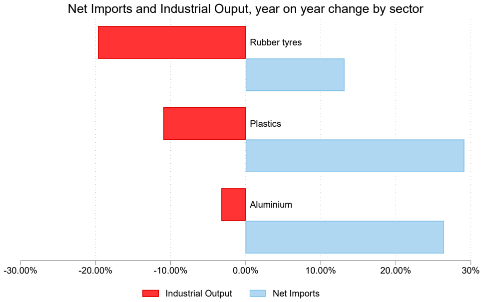


Decoupling: large cuts in energy-intensive sectors but not rest = polar opposite of “cascading effects”



Source: Destatis

Substitution of gas-intensive products via imports



BASF's ammonia production (= very gas-intensive): when gas prices ↑

- drastically cut ammonia production in Luwigshafen, Germany
- But BASF has plant in U.S. ⇒ produce ammonia there, ship it to Germany

Substitution via imports can happen even within same company

Bad for German ammonia production but kills cascading effects

Key Takeaways

1. Automation & AI
   - Powerful framework: task-based models
   - Machines substitute for tasks, not jobs
   - Share of automated tasks shows up as α
   - Macroeconomic and, particularly, distributional effects of AI could be large
   - ... but also large uncertainties
2. The Power of Substitution: Germany without Russian Gas
   - A bit of substitution goes a long way: $\sigma = 0.05$ very different from $\sigma = 0$
   - Large number of examples how this works in practice – see appendix

Not implementing sanctions against Russia sooner and more decisively
= major missed opportunity to help avert enormous human suffering in Ukraine