Integrated Assessment in a Multi-region World with Multiple Energy Sources and Endogenous Technical Change

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May 2017

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- A first attempt, more serious calibration of energy supply and R&D straightforward (we think) but not yet done.

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- Acemoglu, Aghion, Bursztyn and Hemous for directed technical change.

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5. Calibration and analysis of how R&D and carbon taxes interact.

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- Model framework builds on Nordhaus (RICE/DICE), and Golosov et al. (2014).

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- **Oil supplying region** only sells from its finite oil reserv, extracted at zero cost.

Energy production

- **Energy services** provided competitively by representative firm in each region:

$$E_{i,t} = \mathcal{E}(e_{1,i,t}, \ldots, e_{n,i,t}) = \left(\sum_{k=1}^{n} \lambda_k \left(e_{k,t}\right)^{\rho} \right)^{\frac{1}{\rho}}$$

where $e_{1,i,t}$ import of oil to region i, $e_{2,i,t}$, ..$e_{n,i,t}$ produced regionally with linear production function using the final good as input.

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- Oil traded on global market at price $p_{1,t}$.
- Other energy sources produced in each region at cost $p_{k,i,t}$ and not traded.

Resource constraints

- Resource constraint for **oil consuming regions**

$$\begin{aligned} C_{i,t} + K_{i,t+1} &= Y_{i,t} - p_{1,t} e_{1,i,t} - \sum_{k=2}^{n} p_{k,i,t} e_{k,i,t} + (1-\delta) K_{i,t} \\ &= \hat{Y}_{i,t} + (1-\delta) K_{i,t}. \end{aligned}$$

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- for **oil supplying region**

$$\begin{aligned} C_{1,t} &= p_{1,t} \sum_{i=2}^{n} e_{1,i,t} \\ R_{t+1} &= R_t - \sum_{i=2}^{n} e_{1,i,t} \end{aligned}$$

where $R_t \geq 0$ is remaining oil in ground.

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- Golosov et al. (2014), building on IPCC, show that a simple depreciation model for the atmospheric excess stock of carbon S_t well replicates advanced carbon circulation models.

$$S_t = \sum_{s=0}^{t} (1 - d_{t-v}) \sum_{i} M_{i,t}$$

where

$$1 - d_s = \varphi_L + (1 - \varphi_L)\, \varphi_0\, (1 - \varphi)^s$$

measures how much of unit of emissions is left s periods after it was emitted.

Climate and damages

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- $\gamma_{i,t}$ is **lost flow of GDP per unit of carbon** in atmosphere.

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- Regional competitive energy service provider minimizes cost of energy services

$$\min_{e_{k,i,t}} \sum_{k=1}^{n} p_{k,i,t} e_{k,i,t} - P_{i,t} \left(\left(\sum_{k=1}^{n} \lambda_k \left(e_{k,t}\right)^{\rho} \right)^{\frac{1}{\rho}} - E_{i,t} \right)$$

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- Simplify by assuming full depreciation $\delta = 1$. Use period length of a decade. Implies constant savings rate at $\frac{\alpha\beta}{1-\nu}$.

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- Equilibrium determined **sequentially** without forward-looking components. Everything but oil price $p_{1,t}$ determined by closed-form expressions. Can solve in excel sheet.

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- **Negligible deviation**, now keep constant savings rate.

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- Focus on amount of global warming and distributional consequences (between Europe, US, China, Africa and Oil producers).

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- Price of domestic fuels in terms of output good constant in bench-mark (equal tech trends).

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- **3 sources of energy**, oil (finite supply 400 GtC), coal and renewables. Latter two perfectly elastic at prices $p_{k,i,t}$ (later allow R&D to affect these).
- Standard assumptions for discounting and final good production.
- **Elasticity of substitution** between energy sources 0.95 (Stern, 2012).
- Energy suppliers production function calibrated based on observed market prices and quantities. Cost of coal production allowed to differ across regions (World Energy Outlook). Price renewables = current price of oil.
- Price of domestic fuels in terms of output good constant in bench-mark (equal tech trends).
- Regional damage parameters γ_i based on Hassler and Krusell (2012) and Nordhaus. Higher in EU and Africa, lower in China and US.

Experiments - taxes

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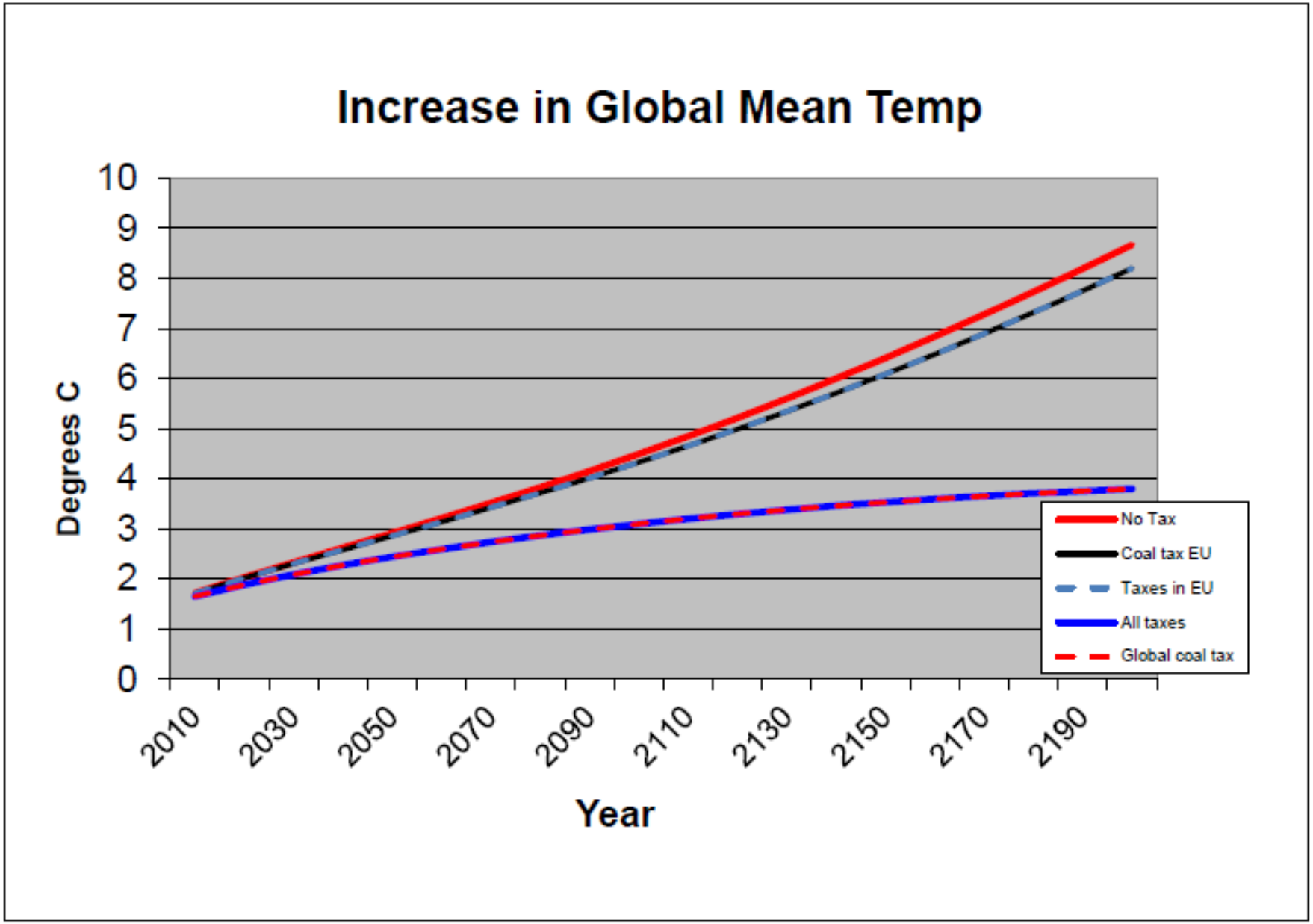
  - Oil producers loose from oil tax (which doesn't change the climate) but not (much) from a coal tax.


Increase in Global Mean Temp
Degrees C
10
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2010
2030
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2110
2130
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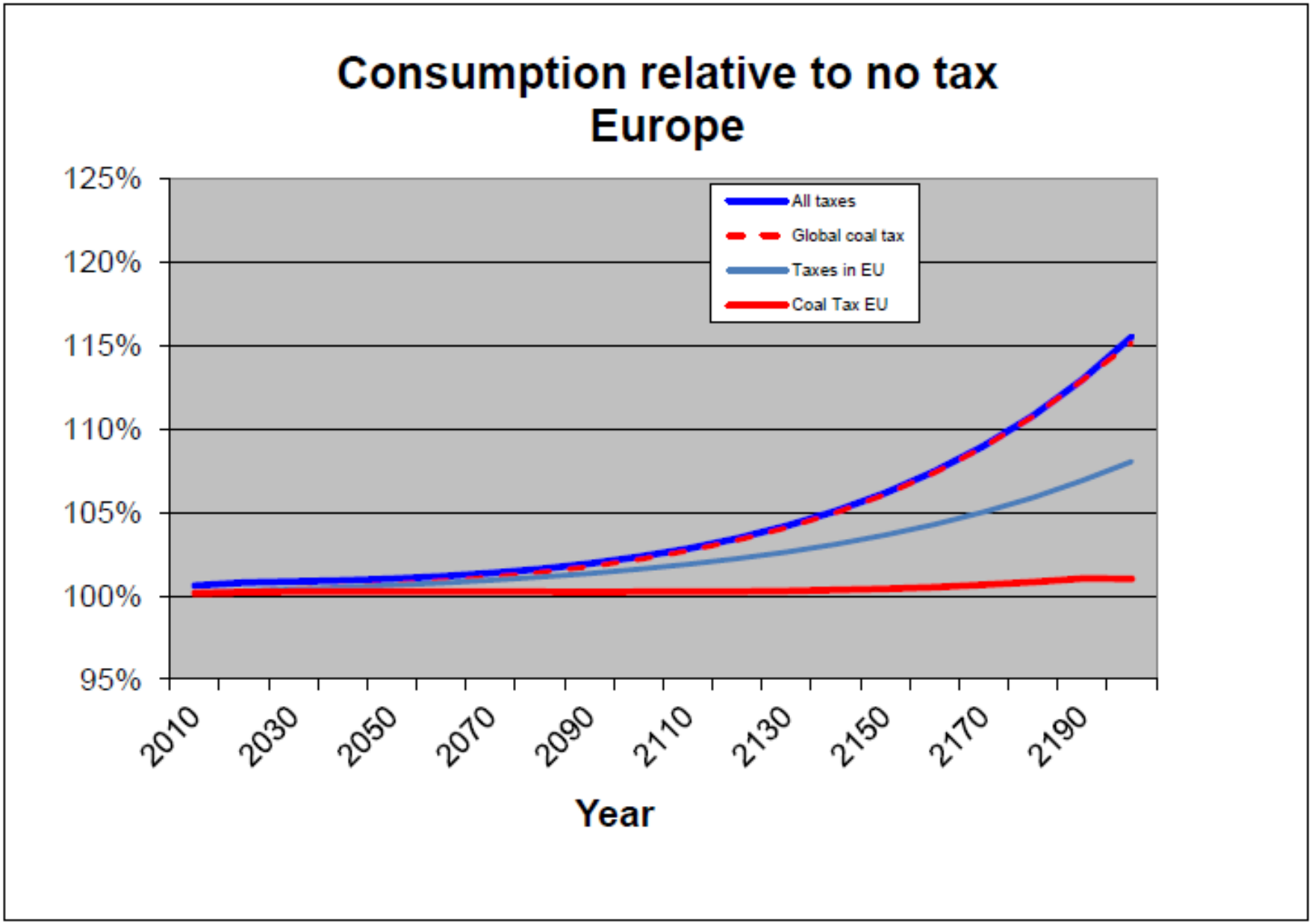
Year
No Tax
Coal tax EU
Taxes in EU
All taxes
Global coal tax


Consumption relative to no tax
Europe
125%
120%
115%
110%
105%
100%
95%
All taxes
Global coal tax
Taxes in EU
Coal Tax EU
2010
2030
2050
2070
2090
2110
2130
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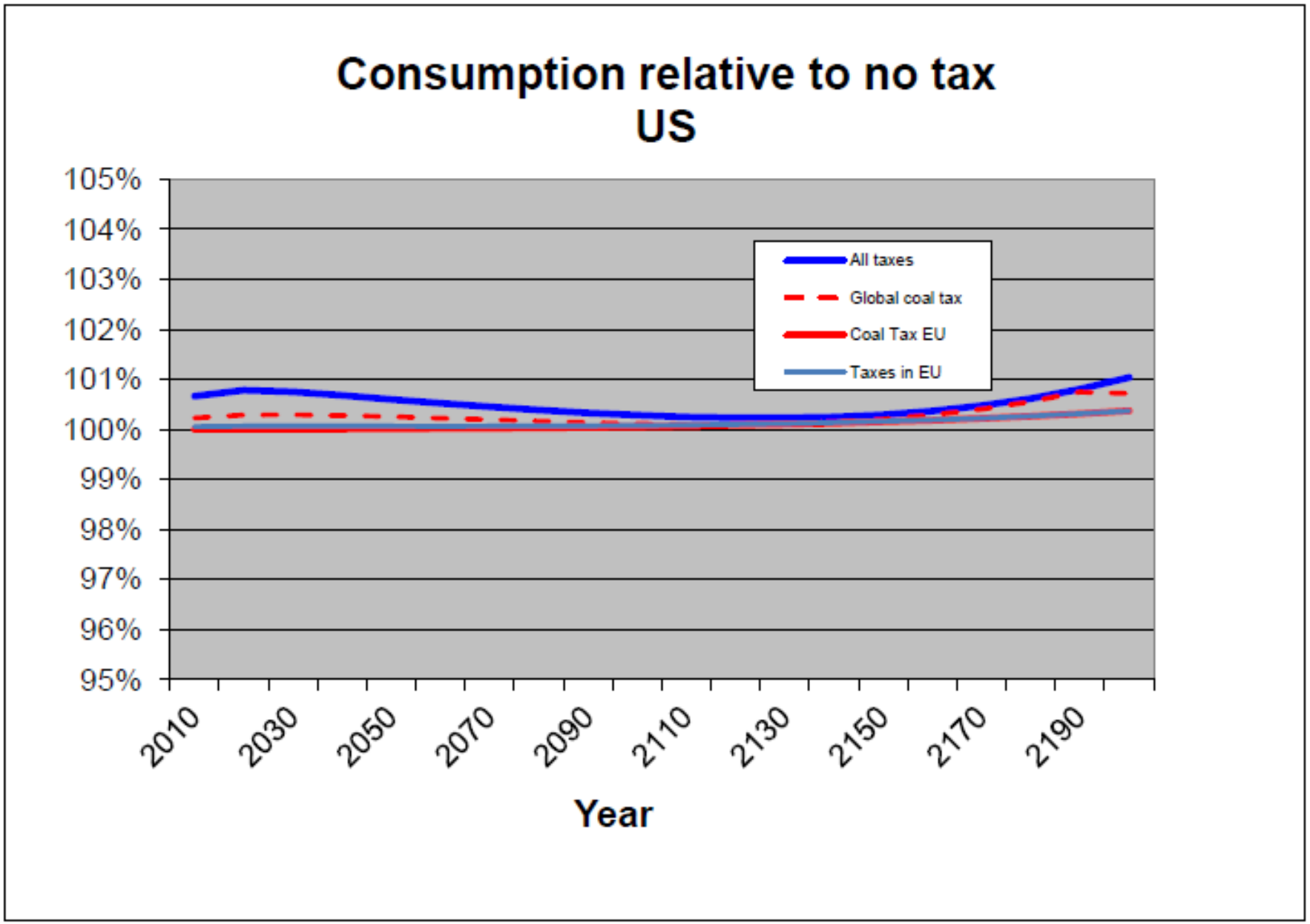
2170
2190
Year


Consumption relative to no tax
US
105%
104%
103%
102%
101%
100%
99%
98%
97%
96%
95%
All taxes
Global coal tax
Coal Tax EU
Taxes in EU
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2030
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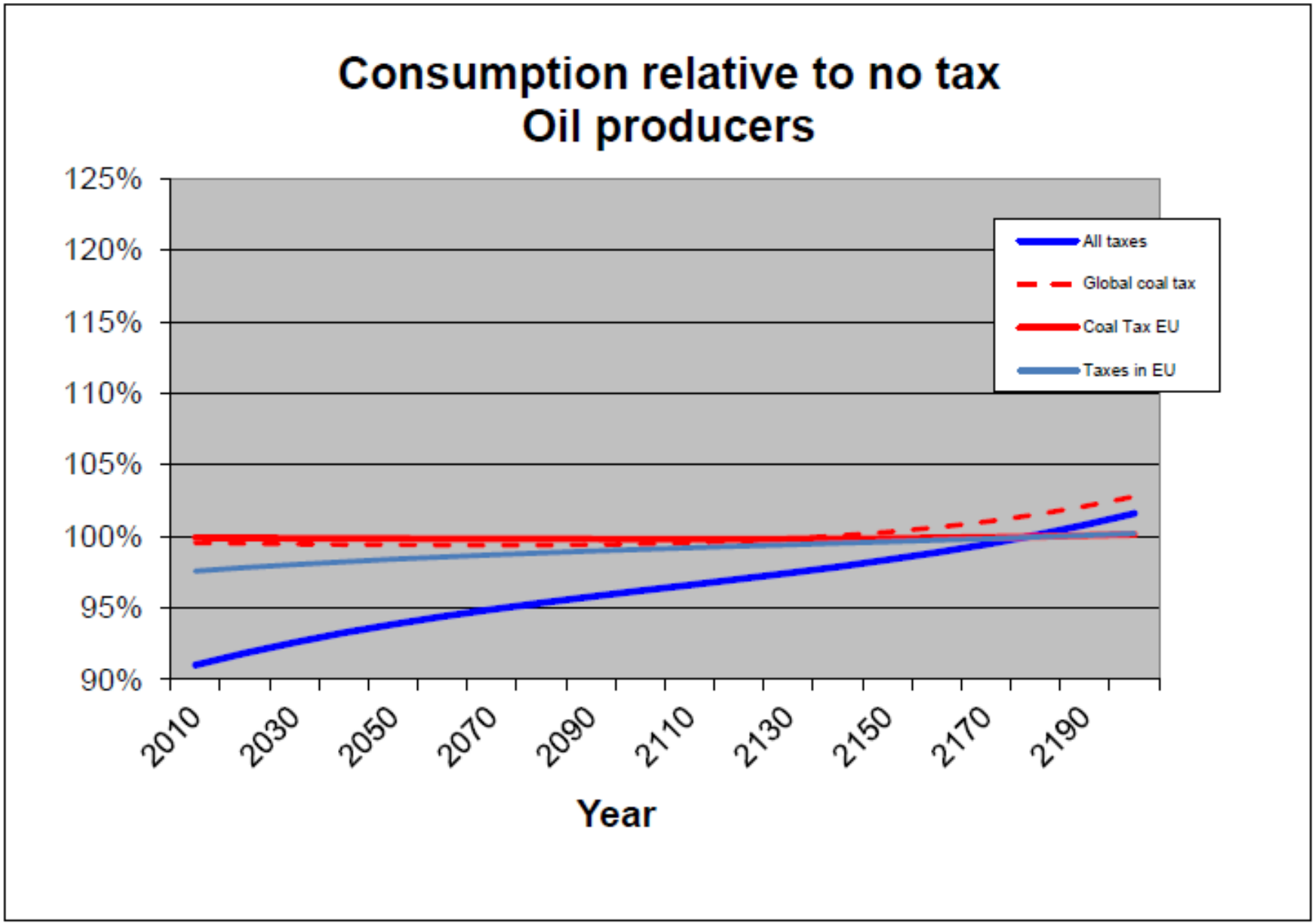
2190
Year


Consumption relative to no tax
Oil producers
125%
120%
115%
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105%
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2010
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2050
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Experiment - tech change

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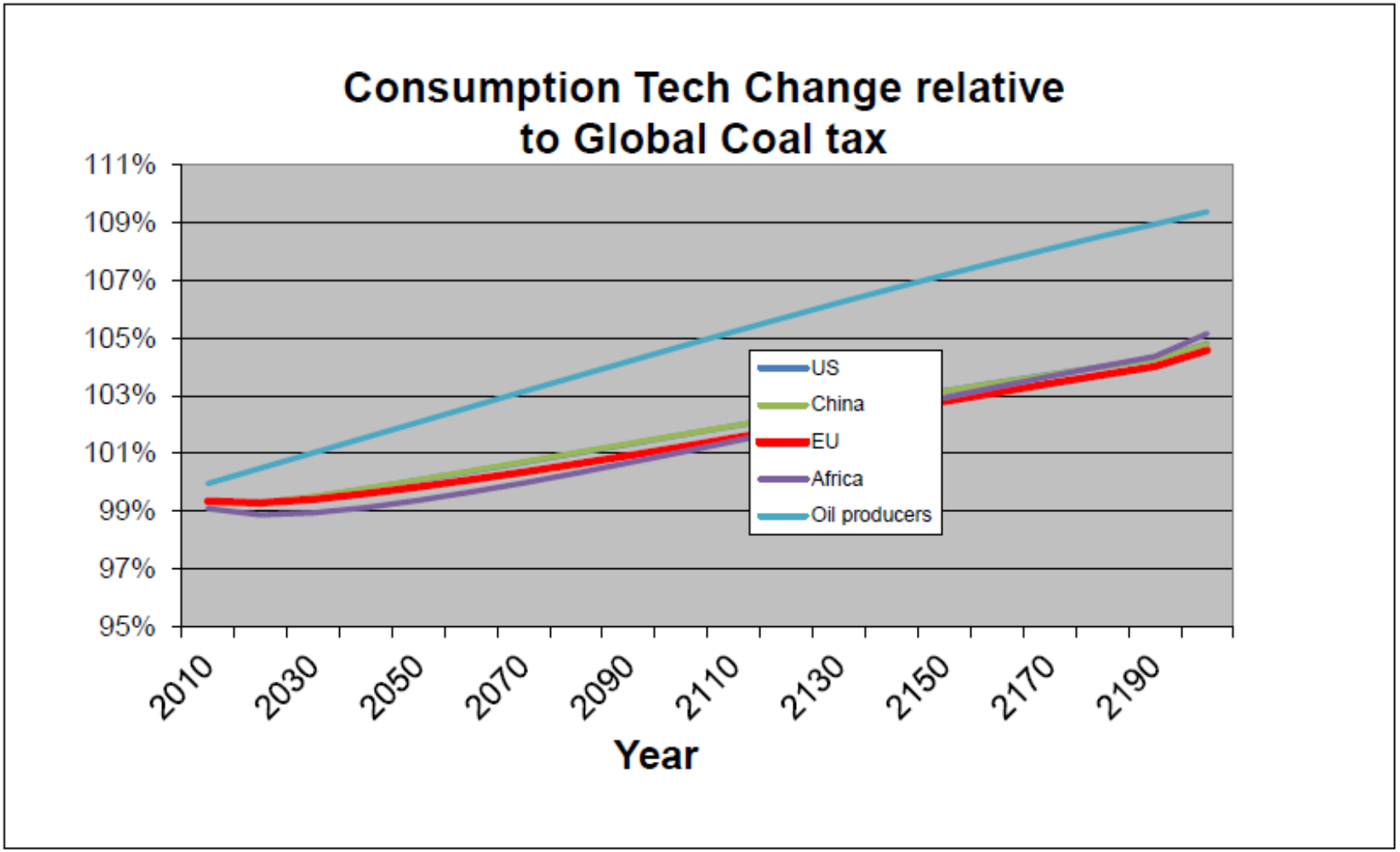
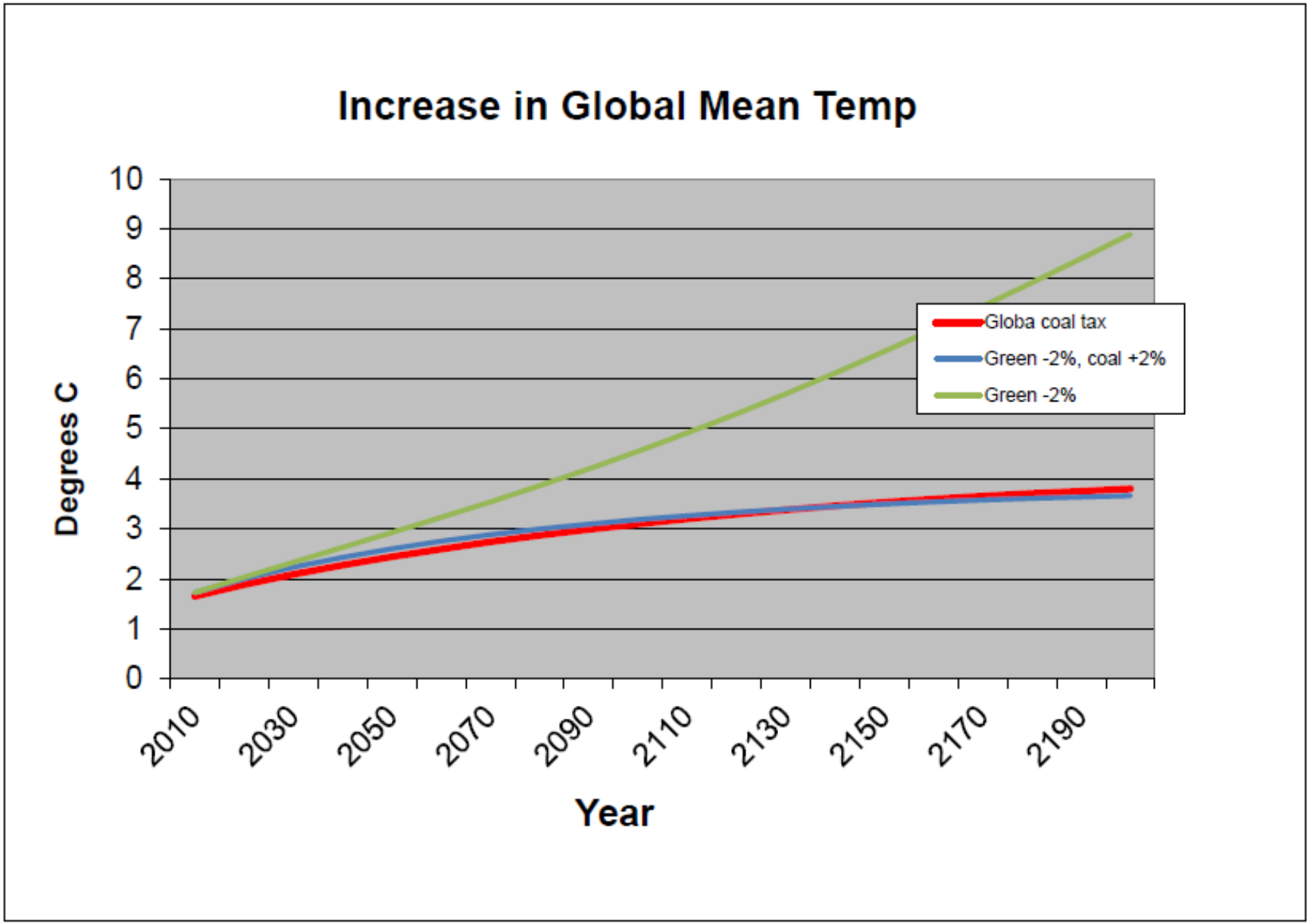
  - Only green tech change does little for climate, relative price of coal must increase!


Consumption Tech Change relative to Global Coal tax
111%
109%
107%
105%
103%
101%
99%
97%
95%
2010
2030
2050
2070
2090
2110
2130
2150
2170
2190
Year
US
China
EU
Africa
Oil producers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Green -2%, coal +2%
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- Involves only energy service providers, nothing else is changed in model (including simple recursive structure).

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- Note that direct effect of taxes is to *increase* marginal value of cost reductions (LHS). Also indirect effect in opposite direction coming from $\frac{de^*_{k,i,t}}{d\tau_{k,i,i}} < 0$.

No effect of taxes on after tax costs!

- Using expression for optimal supply $e^*_{k,i,t}$ (same as before) in $(1+\tau_{k,i,t})\, e^*_{k,i,t} = \frac{\Lambda_{i,t}}{p_{k,i,t}}$ yields

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- **R&D completely undo taxes!** (When FOC is satisfied). Intuition, the two effects discussed above cancel each other. Suggest per unit taxes are not neutral.

Per unit tax

- If tax is per unit, no longer closed-form solution.

$$\frac{p_{2,i,t}\left(\tau_{2,i,t}+p_{2,i,t}\right)^{\frac{-1}{1-\rho}}}{p_{3,i,t}\left(\tau_{3,i,t}+p_{3,i,t}\right)^{\frac{-1}{1-\rho}}}=\frac{\varepsilon_2}{\varepsilon_3}\left(\frac{\lambda_2}{\lambda_3}\right)^{\frac{1}{\rho-1}}$$

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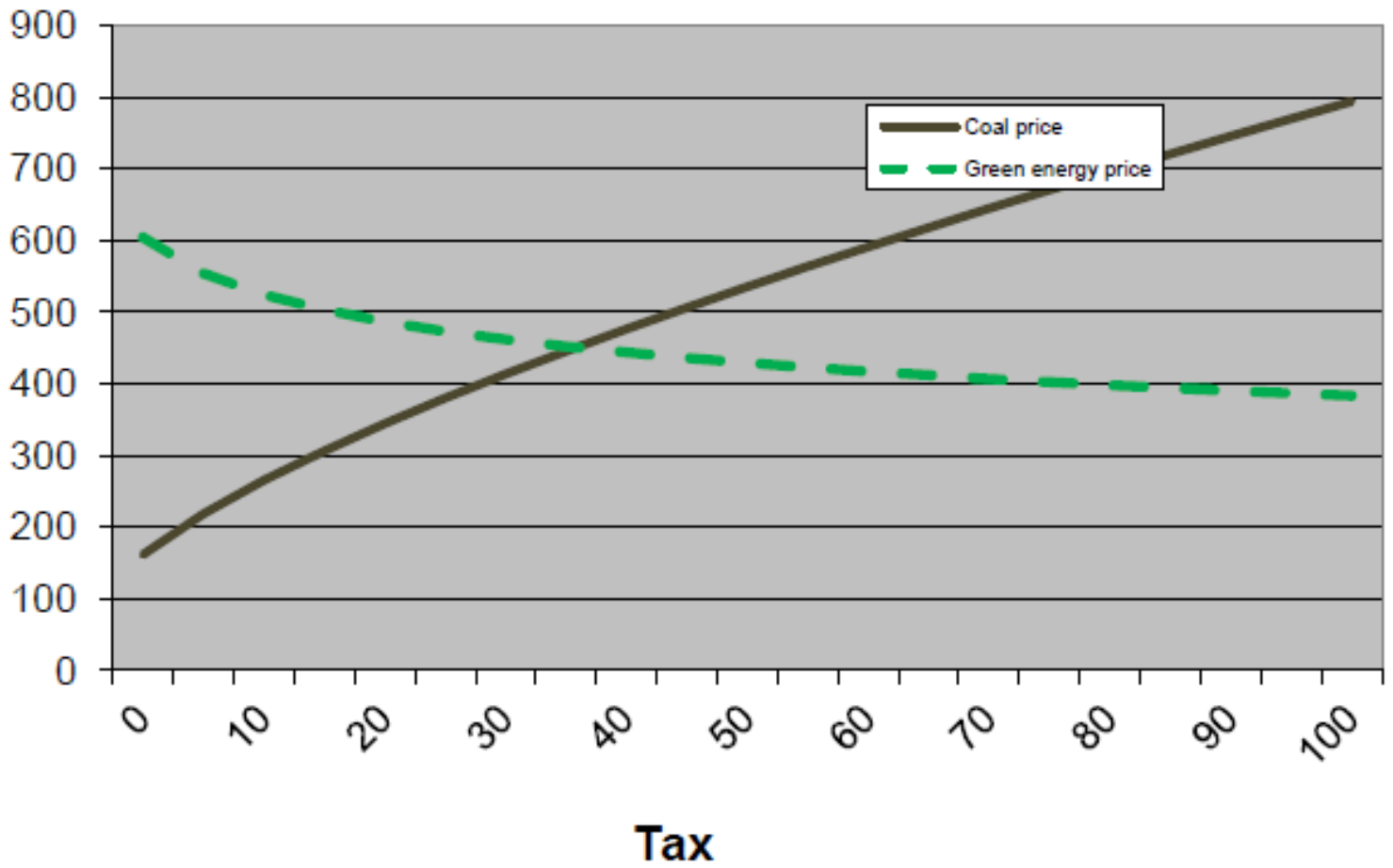
- Use previous calibration for Europe and assume FOC is satisfied (latter gives $\varepsilon_3=0.778$ and $\varepsilon_2=0.222$, more difficult to reduce cost of green).


Coal and Green energy prices in interior R&D optimum
900
800
700
600
500
400
300
200
100
0
Coal price
Green energy price
0
10
20
30
40
50
60
70
80
90
100
Tax

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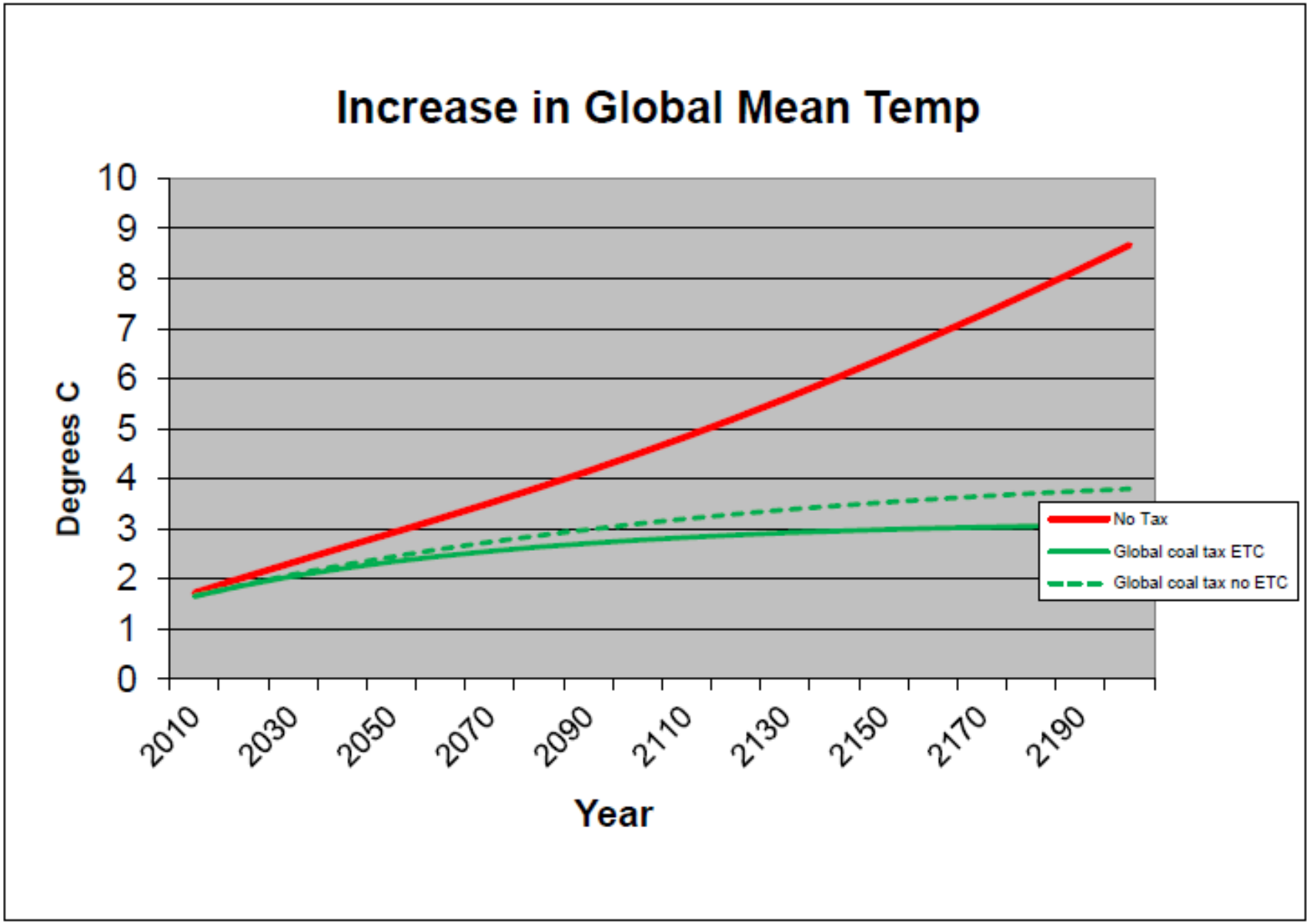
- Would result also with taxes much smaller than optimal!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Year
No Tax
Global coal tax ETC
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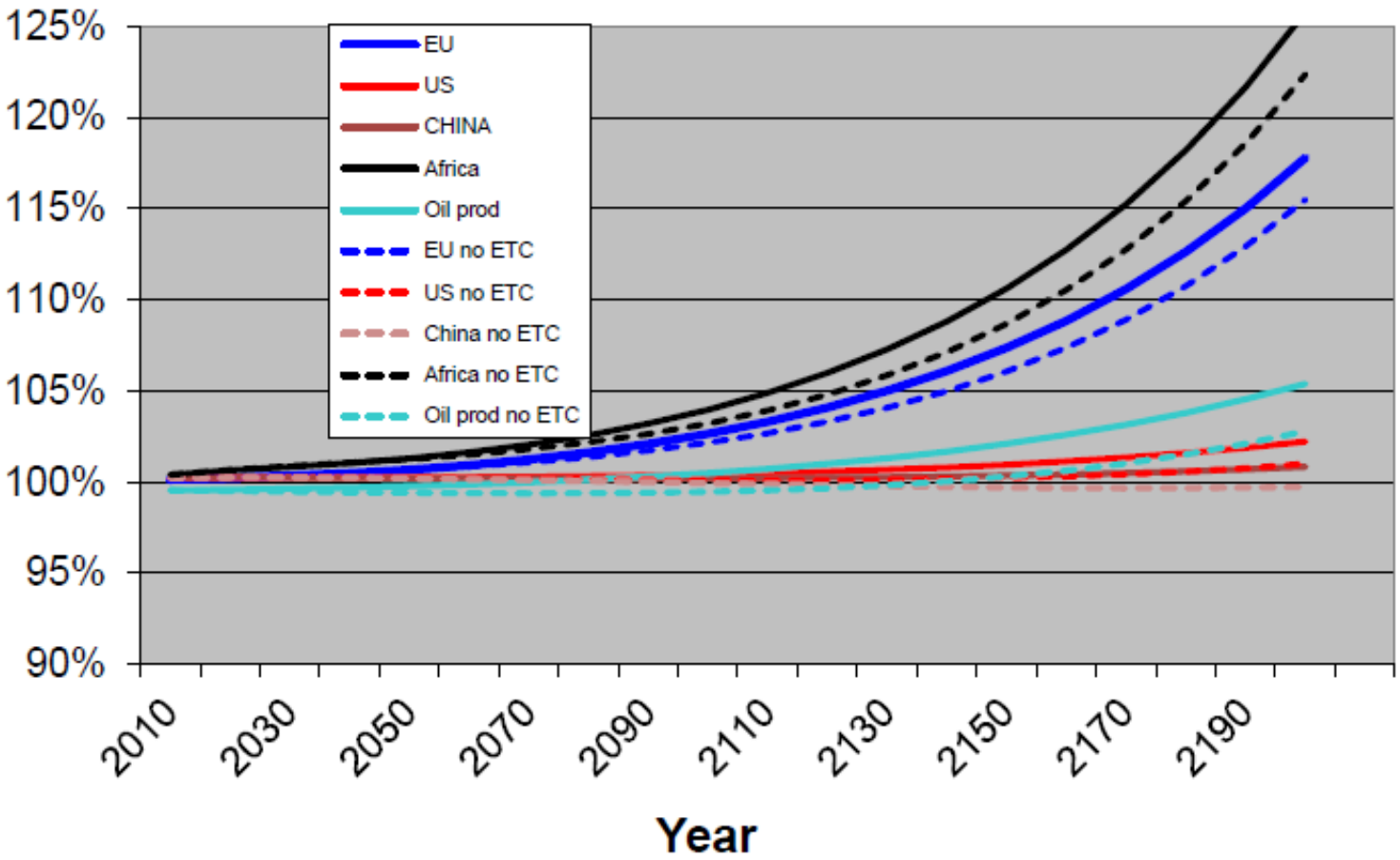
Consumption with coal tax relative to no tax



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- Lot's of interesting work ahead!
  1. More serious calibration of energy supply including fracking and other non-conventional sources of fossil fuel as well as existing taxes and subsidies.
  2. Allow higher elasticity between some fuels, e.g., non-conventional and conventional oil/gas. Endogendous tech change can make them a backstop - longlived price cap. Big threat to climate.
  3. Trade in some of these energy sources.
  4. Serious calibration of R&D – not relying on log-linear extrapolation.
  5. More regional heterogeneity.
  6. Much more!