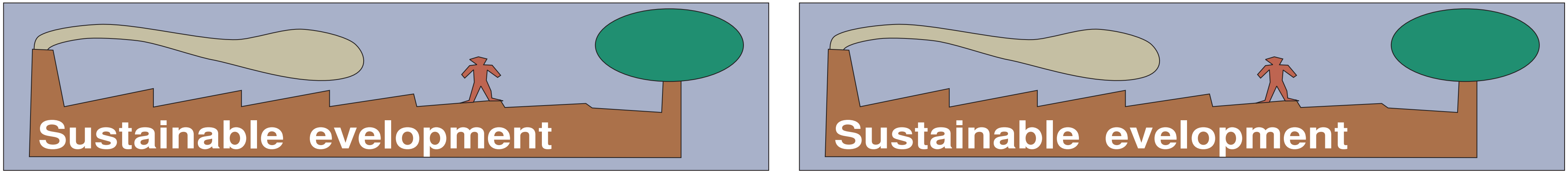


Core lecture 4

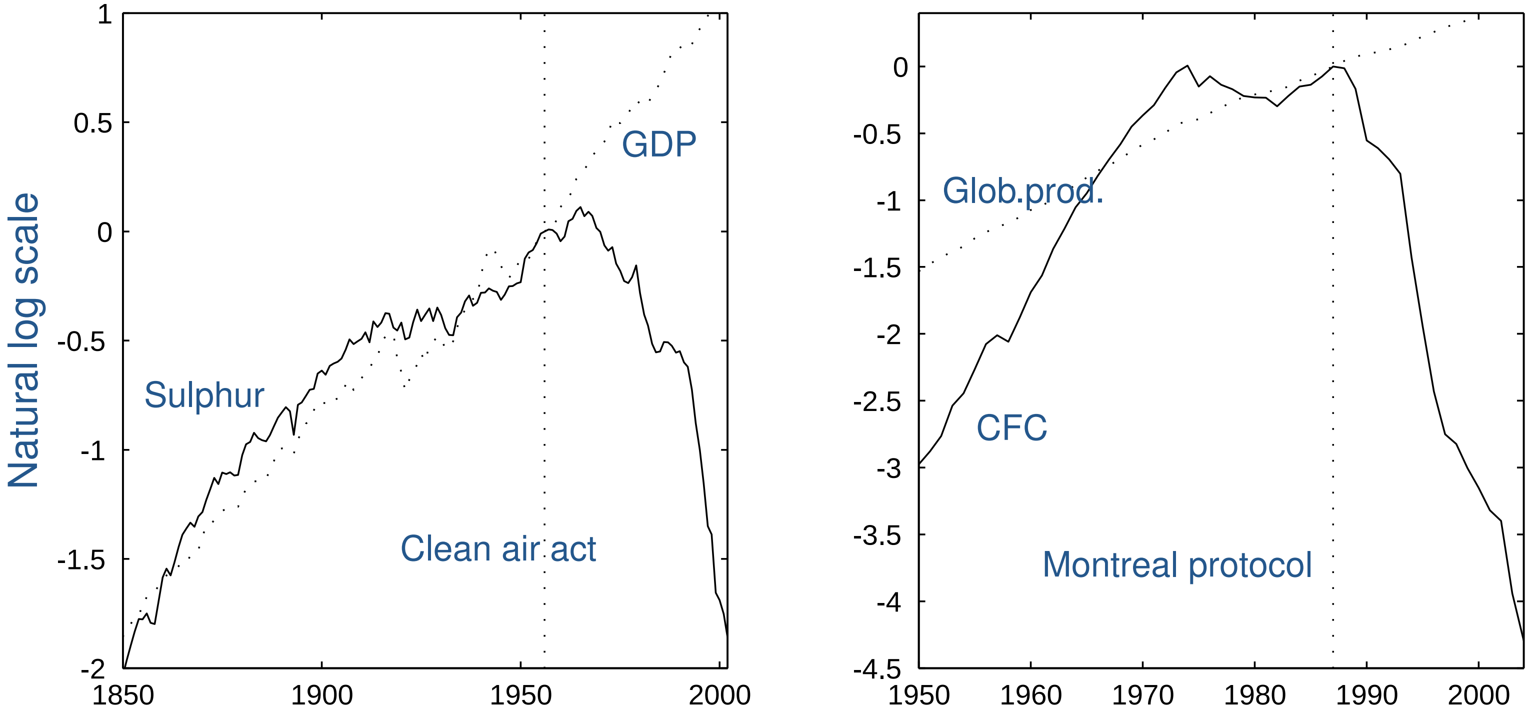
# Pollution

# The EKC and substitution between alternative inputs

Based on Hart (2020), *Growth, pollution, policy!*.

# Empirical observations and literature

# Empirical observations and literature



UK Sulphur emissions compared to total UK GDP, and global CFC production (CFC11+CFC12) compared to total global product.

# Empirical observations and literature

Grossman and Krueger is the seminal work.

In the empirically oriented EKC literature there is strong support for the idea that when the flow of a single pollutant in a single country is plotted against time, that flow will in most cases first tend to rise, and later (if enough time has passed) decline. See for instance Grossman and Krueger and Selden et al. (1999).

However, if we compare paths for the same pollutant across different countries, it is hard to find clear patterns; the turning point is neither at a given time, nor at a given level of per-capita GDP. For instance, Stern (2004) concludes [p1435] that '[t]here is little evidence for a common inverted U-shaped pathway that countries follow as their income rises'.

# Empirical observations and literature

Despite more than 20 years of research, there is still no widely accepted theoretical explanation for the phenomenon. One reason for this is that researchers building theoretical models have fallen into the trap of treating pollution as an input to production, rather than as a by-product of the use of natural resources, following a tradition going back at least as far as the text book of Baumol and Oates (1975).

If we think of pollution as an input in a Cobb–Douglas production function, then we know that the factor share of pollution must be constant. And if we let the marginal damage caused by pollution track income (a natural assumption) then the flow of pollution should be constant as the economy grows. This is like our DHSS-style model with land, in which the price of land tracks the growth rate. Except that here it is the price which is tied to the growth rate, and this leads (endogenously) to a constant flow of pollution.

# Empirical observations and literature

When we treat pollution as a by-product of natural-resource use (following Murty et al. (2012)), the analysis changes completely. The social costs of natural resource use are then the sum of extraction costs and the damage costs of the concomitant pollution.

At low income the pollution damages are small and the (constant) extraction cost dominates. And because the natural resource is an input in a Cobb–Douglas production function, natural resource consumption increases with growth, as do polluting emissions.

As income increases, so does the WTP to avoid pollution. The social cost of natural-resource use starts to rise, and resource use levels off. However, more importantly, if there is a cleaner (but more expensive) alternative resource, there will come a point at which this resource is preferred, and pollution falls dramatically.

# The specified model

# The specified model

$$
\begin{aligned}
Y(t) &= [A_L(t)L(t)]^{1-\alpha}R(t)^{\alpha}e^{-P(t)^{\phi}},\\
g &= \dot{A}_L(t)/A_L(t) + \dot{L}(t)/L(t),\\
R &= \sum_{j=1}^{n} D_j,\\
P &= \sum_{j=1}^{n} \psi_j D_j.
\end{aligned}
$$

The cost of a unit of input $j$ is $w_j$.

# The specified model

$$Y(t) = [A_L(t)L(t)]^{1-\alpha} R(t)^{\alpha} e^{-P(t)^{\phi}},$$

$$g = \dot{A}_L(t)/A_L(t) + \dot{L}(t)/L(t),$$

$$R = \sum_{j=1}^{n} D_j,$$

$$P = \sum_{j=1}^{n} \psi_j D_j.$$

We can interpret alternative technologies $j$ and $k$ simply as alternative resource inputs, for instance low- and high-sulfur coal for electricity generation. However, a third technology $l$ could be high-sulfur coal combined with flue-gas desulfurization (FGD).

# The specified model

$$
\begin{aligned}
Y(t) &= [A_L(t)L(t)]^{1-\alpha} R(t)^{\alpha} e^{-P(t)^{\phi}}, \\
g &= \dot{A}_L(t)/A_L(t) + \dot{L}(t)/L(t), \\
R &= \sum_{j=1}^{n} D_j, \\
P &= \sum_{j=1}^{n} \psi_j D_j.
\end{aligned}
$$

If the input is simply a natural resource then we can think of it as being extracted competitively from a large homogeneous stock, with each unit extracted requiring $w_j$ units of final good as input. But for technology $l$ the price $w_l$ would be $w_k$ plus the unit cost of FGD, and unit emissions $\psi_l$ would be $\psi_k \times$ the fraction remaining after FGD.

# The specified model

$$Y(t) = [A_L(t)L(t)]^{1-\alpha} R(t)^\alpha e^{-P(t)^\phi},$$
$$g = \dot{A}_L(t)/A_L(t) + \dot{L}(t)/L(t),$$
$$R = \sum_{j=1}^{n} D_j,$$
$$P = \sum_{j=1}^{n} \psi_j D_j.$$

We denote aggregate production net of extraction costs as $Z$, so

$$Z = (A_L L)^{1-\alpha} \left( \sum_{j=1}^{n} D_j \right)^\alpha e^{-(\sum_{j=1}^{n} \psi_j D_j)^\phi} - \sum_{j=1}^{n} w_j D_j.$$

# The specified model

Social planner; two technologies.

$$Z = (A_L L)^{1-\alpha} \left( \sum_{j=1}^{n} D_j \right)^{\alpha} e^{-(\sum_{j=1}^{n} \psi_j D_j)^{\phi}} - \sum_{j=1}^{n} w_j D_j .$$

FOC $D_1 : \alpha Y/(D_1 + D_2) = w_1 + \phi(\psi_1 D_1 + \psi_2 D_2)^{\phi-1} \psi_1 Y.$

And FOC $D_2 : \alpha Y/(D_1 + D_2) = w_2 + \phi(\psi_1 D_1 + \psi_2 D_2)^{\phi-1} \psi_2 Y.$

MB=MC. Benefits identical, costs differ. Costs: input costs $w_j$ and damage costs $\phi P^{\phi-1} \psi_j Y$.

# The specified model

Start with the case in which $w_1 < w_2$ and $\psi_1 < \psi_2$, so $D_1$ is both cheaper and cleaner, and $D_2$ will never be used.

$$\text{FOC } D_1 : \alpha Y/(D_1 + D_2) = w_1 + \phi(\psi_1 D_1 + \psi_2 D_2)^{\phi-1}\psi_1 Y.$$

When only input $D_1$ is used, from any given initial state (defined by $A_L(0)L(0)$), $P$ increases monotonically and approaches a limit of $\bar{P} = (\alpha/\phi)^{1/\phi}$. If we let $A_L(0)L(0)$ approach zero then the initial growth rate of $P$ approaches $g$ from below.

# The specified model

The shadow price of the polluting input to the social planner is the sum of extraction cost and marginal damages. The extraction cost is constant, whereas marginal damages increase linearly in $Y$.

So when $Y$ is small the shadow price is approximately equal to the constant extraction cost, and both resource use and polluting emissions track growth.

As $Y$ increases, marginal damages increase and hence the shadow price of using the polluting input increases.

When $Y$ is large marginal damages dominate the extraction cost, the shadow price of using the input grows at the overall growth rate, and emissions (and input use) are constant.

So we have a transition from emissions tracking growth towards (in the limit) constant emissions.

# The specified model

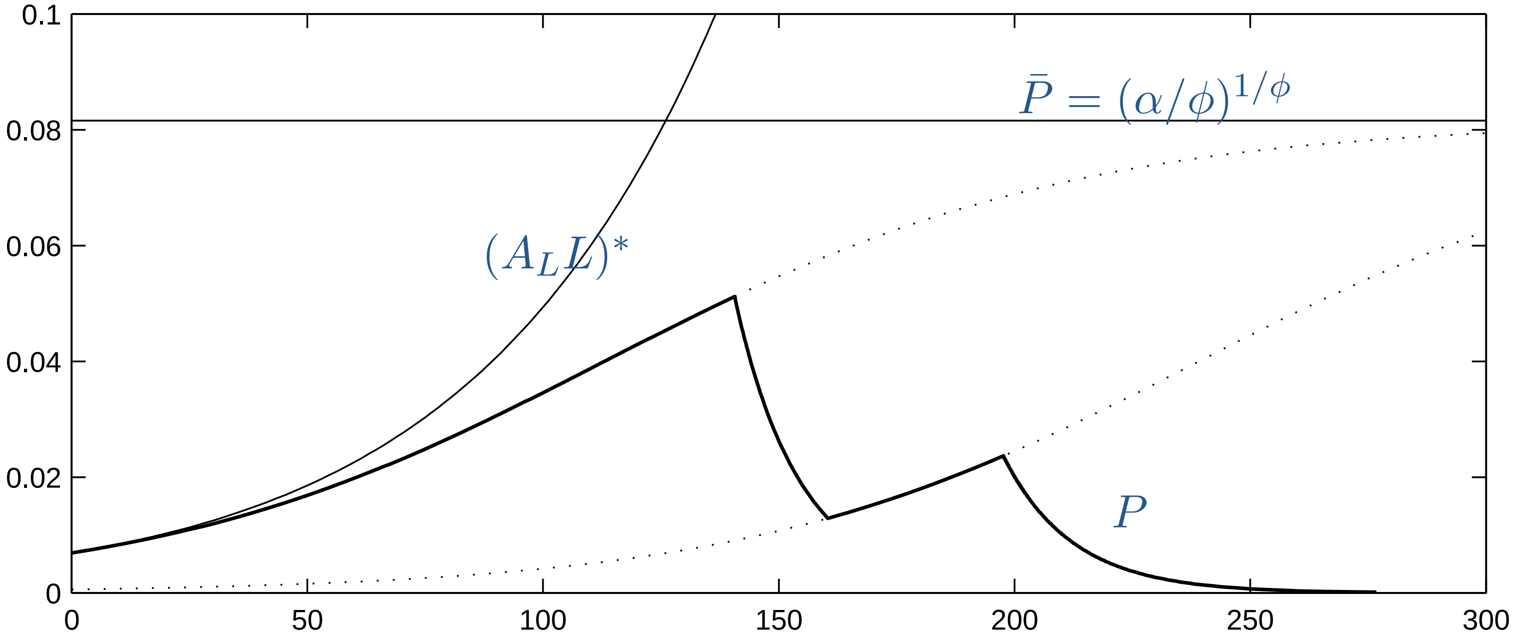
Now we take the more interesting case when technology 2 is more expensive but clean, i.e. $\psi_2 = 0$. In this case, as $Y$ increases, the increasing importance of pollution damages does not just lead to pollution abatement within technology 1—i.e. the substitution of labour–capital for $D_1$ in production—it also narrows the gap between the social costs of $D_1$ (cheap and dirty) and $D_2$ (expensive but cleaner). At some point the social costs are equal, and a transition to the cleaner technology begins.

From this point on the transition is gradual, because marginal damages decrease as emissions decrease (as long as $\phi > 1$).

$$\alpha Y/(D_1 + D_2) = w_1 + \phi(\psi_1 D_1 + \psi_2 D_2)^{\phi-1}\psi_1 Y.$$
$$\alpha Y/(D_1 + D_2) = w_2 + \phi(\psi_1 D_1 + \psi_2 D_2)^{\phi-1}\psi_2 Y.$$

# The specified model

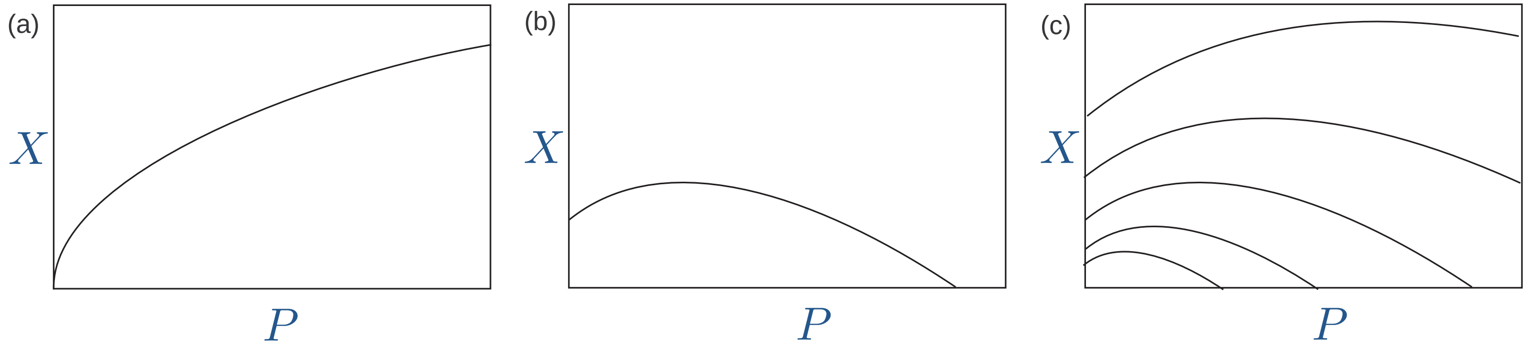
In the figure we illustrate the development of the economy in a specific case with three technologies, the third of which is perfectly clean. The dotted lines show the paths of $P$ which would be followed if (respectively) only technologies $1$ and $2$ were available.



# A graphical approach

# A graphical approach

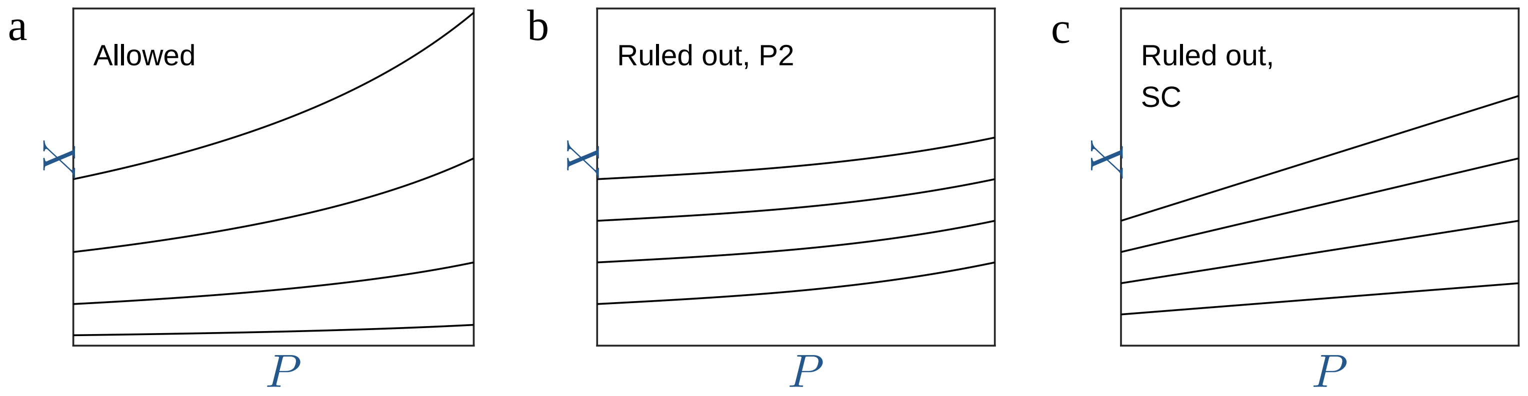
PPFs over production and pollution.



PPFs. The PPF in (a) is not allowed because there is no turning point; the PPF in (b) is allowed; in (c) we see a set of PPFs for different productivity levels.

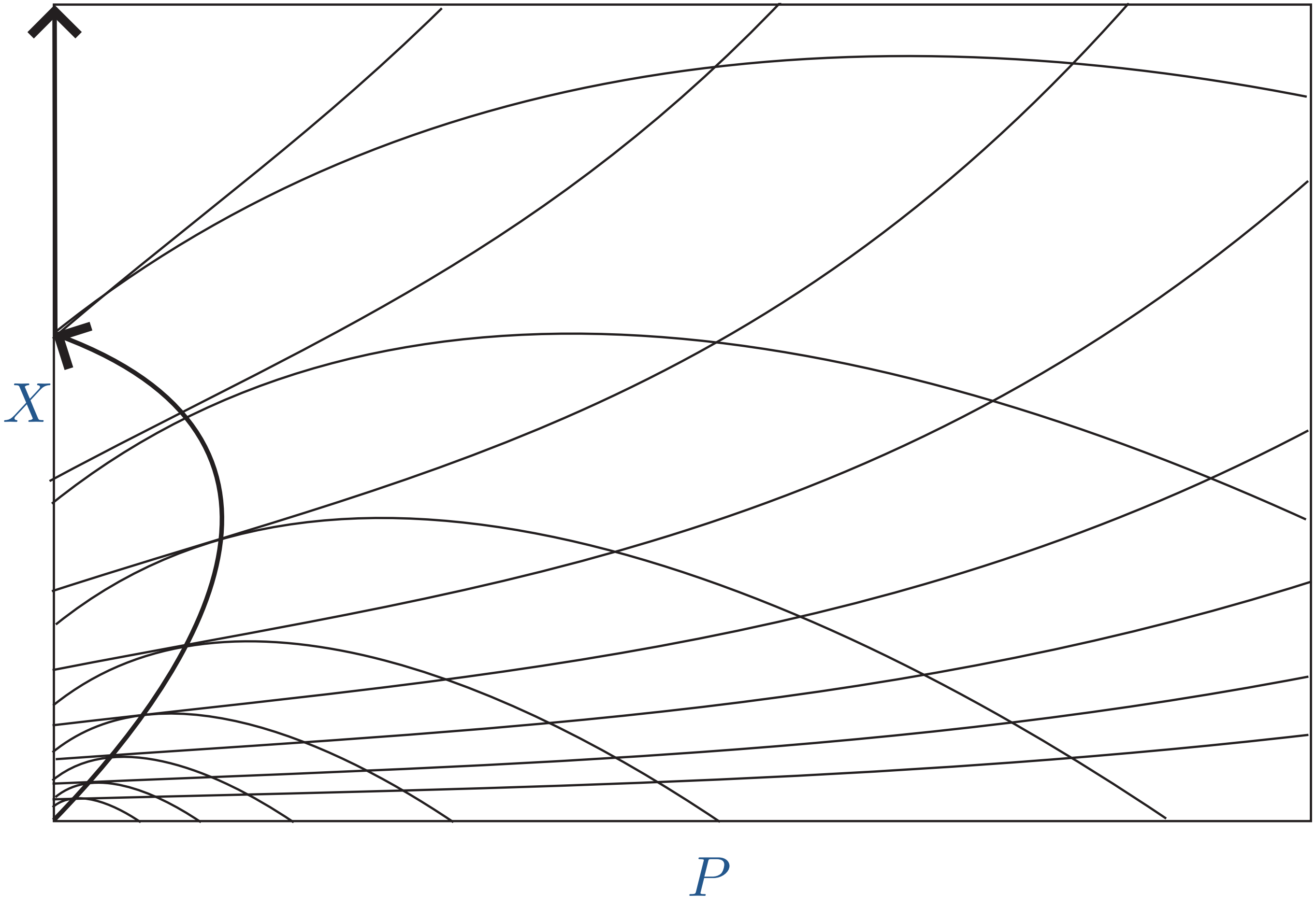
# A graphical approach

Indifference curves over production and pollution.



Three sets of indifference curves. The second is ruled out because $\mathrm{d}X/\mathrm{d}P$ does not increase in $X$, implying that the WTP to remove a unit of pollution does not increase in income, and the third is ruled out because the curves are not strictly convex.

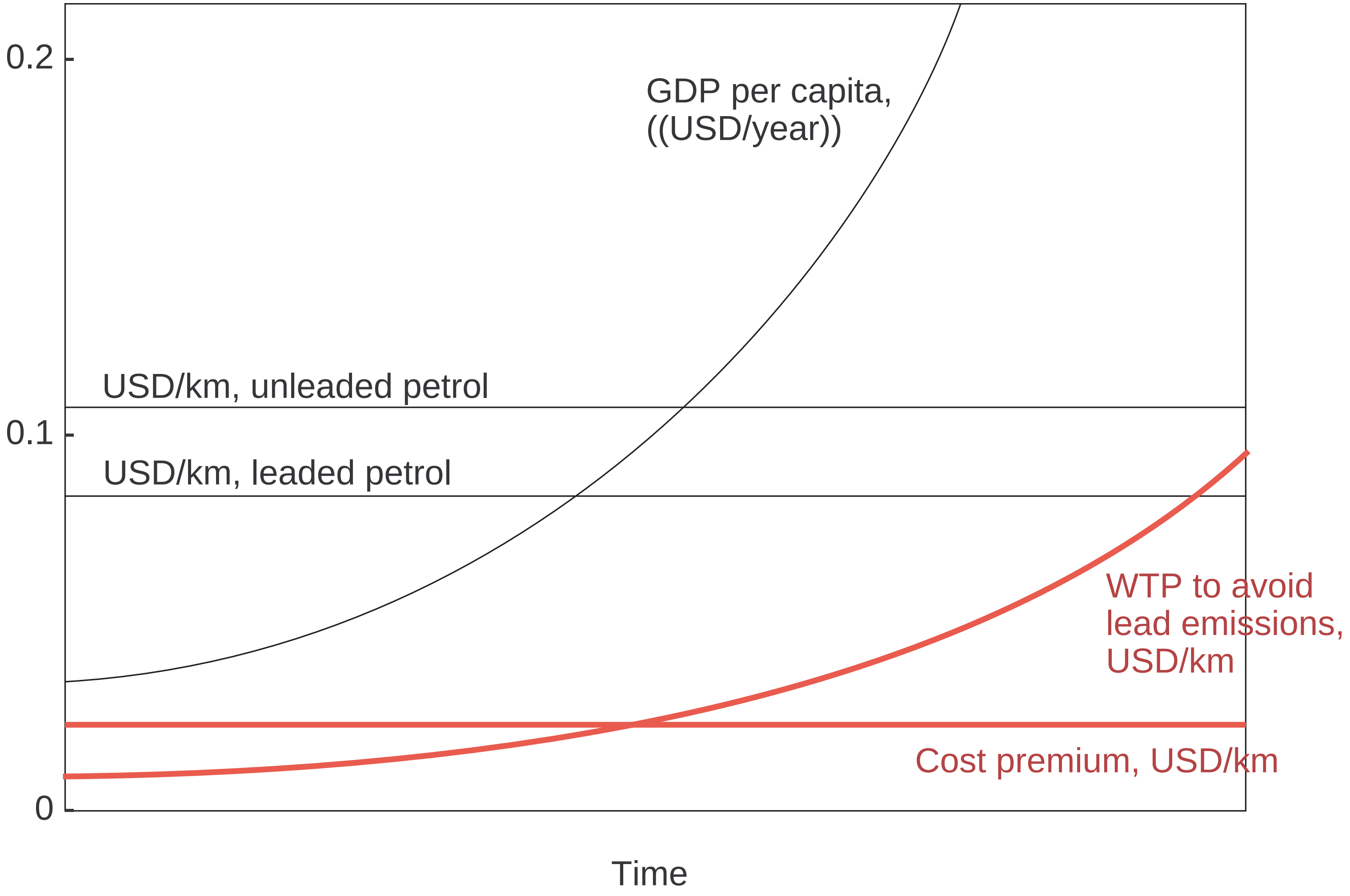
# A graphical approach



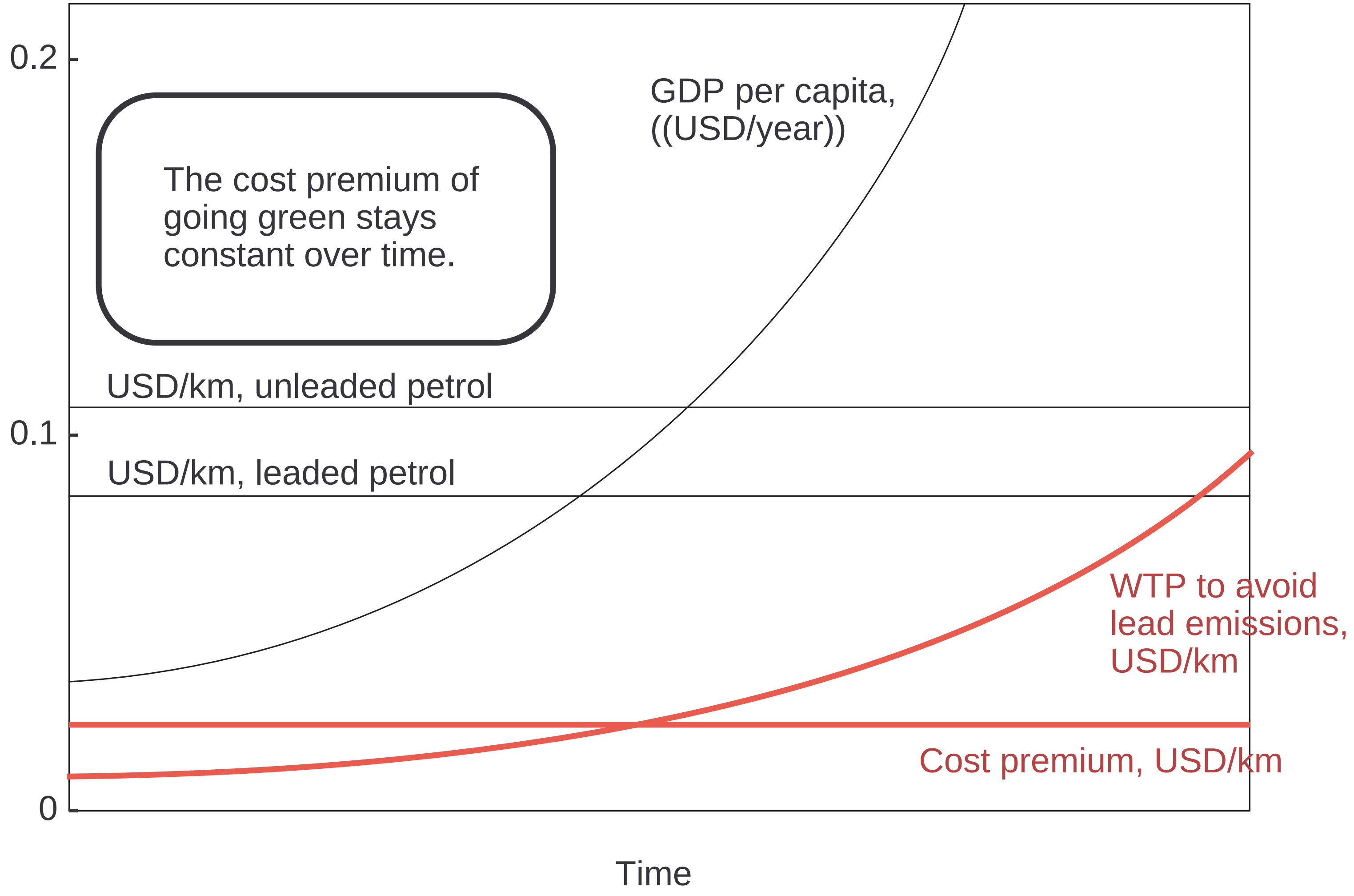
The rise and fall of $P$ as productivity increases.

# Lead in petrol

# Lead in petrol

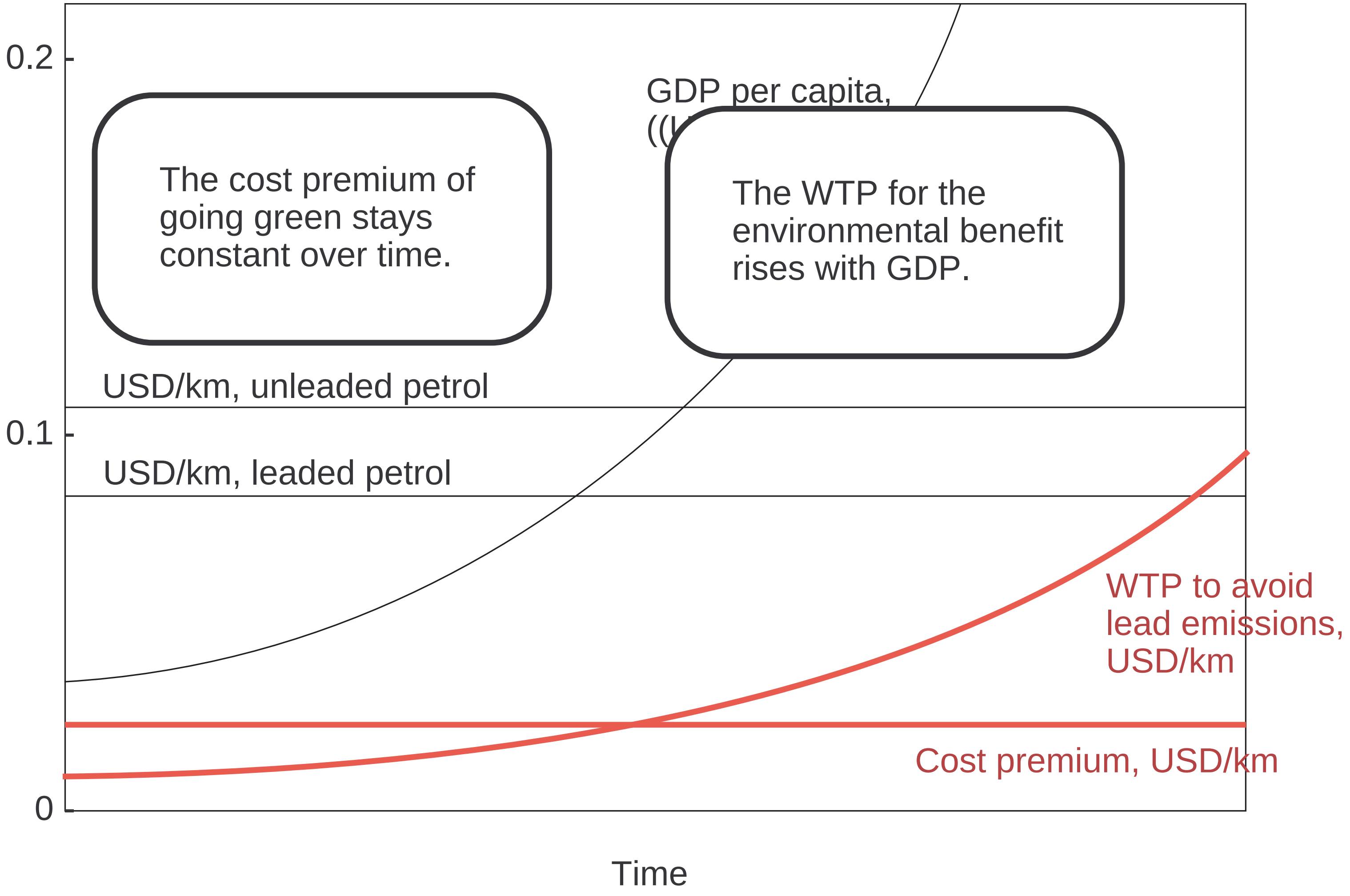


# Lead in petrol



The cost premium of going green stays constant over time.

# Lead in petrol



The cost premium of going green stays constant over time.

The WTP for the environmental benefit rises with GDP.

# Solow's mechanisms

# Solow’s mechanisms

How does the model relate to Solow’s mechanisms!?

# Application of the model

# Short-lived local pollutants

# Short-lived local pollutants

On the face of it the model seems a good fit for short-lived local pollutants.

Consider lead in petrol. Does the data fit the model? Why/why not? Relate to Solow's mechanisms.

Consider emissions of nitrates and phosphates to water from agricultural land. (See for instance Segerson and Walker (2002)). How can we explain what has happened in terms of the data?

Think of (through) other cases!

# Long-lived global pollutants

# Long-lived global pollutants

Long-lived pollutants tend to spread, hence they are also likely to affect multiple countries or even the entire world, as in the case of $CO_2$ and many other pollutants which are very long-lived and *uniformly mixing*, i.e. it makes no difference to damages where in the world they are emitted.

This introduces two complications compared to our model.

1. We now have a dynamic problem rather than a static one;
2. Optimal regulation requires global agreements.

# Long-lived global pollutants

The need for global agreements is an example of a reason why pollution may not, in practice, be optimally priced.

Others include that the marginal external cost may be both unknown (due to imperfect information) and continually changing (as shown by our model), and that emissions taxes or tradable permit systems may be costly to implement (as in the case of agricultural emissions). What are the implications of dropping the first-best assumption?

Assume that pollution is underpriced by some factor no greater than $N$. What happens?

# Long-lived global pollutants

Now assume a stock pollutant. How could we analyse this? What results should we expect from a model allowing for pollution stocks?

# Long-lived global pollutants

Discuss what we can learn from the model about how future growth will affect $CO_2$ emissions and the climate.

# Policy implications

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If shifting between technologies—and in particular the abandonment of obsolete dirty technologies—is key to cleaning up, what does this tell us about policy? Pigou?

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Think about cases where a social planner would already choose clean alternatives. For instance, not using fossil fuels (especially coal) for electricity generation. What should a regulator do?

# Policy implications

If shifting between technologies—and in particular the abandonment of obsolete dirty technologies—is key to cleaning up, what does this tell us about policy? Pigou?

Think about cases where a social planner would already choose clean alternatives. For instance, not using fossil fuels (especially coal) for electricity generation. What should a regulator do?

And think also about cases in which clean alternatives won't be ready for a decade or more, such as for air travel. What should a regulator do here?