Traveling Along the Environmental Kuznets Curve

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Introduction

Does economic growth bring improving or worsening environmental performance? Proponents of the idea of the *Environmental Kuznets Curve* hypothesis say that both occur, but at different times of the development process. Specifically, the hypothesis is that at low incomes, environmental impact per dollar GDP increases with increasing GDP per capita, while at high incomes it declines. This is a plausible and intriguing idea, and has received a great deal of attention.[1] The current consensus is that some pollutants (such as SO_x emissions) seem to follow an environmental Kuznets curve, while others do not (carbon emissions). It is not a general trend, and also seems not to be the dominant trend for environmental pressures in general. Nevertheless, as a story of how development could occur – a scenario narrative – it is of great interest. In those cases where it does (or might) apply, it leads to qualitatively different outcomes than a more naive, growth-rate–based analysis might suggest. It is interesting to study its implications in a quantitative scenario, both on its own merits and as an example of quantifying a scenario narrative.

In this case study, a particular form for the Kuznets curve is proposed. It is a flexible formulation with a small number of parameters. It is well-behaved at all income levels and connects to the more conventional approach based on income elasticities of pollution intensities by asymptotically approaching a constant-elasticity function at low and high incomes. Scenario analysts interested in exploring the implications of the Environmental Kuznets Curve hypothesis may find the general functional form proposed here of use in their own work. Also, an explicit scenario is presented in which the environmental Kuznets curve formula proposed here is implemented using the IPAT-S scenario scripting language. The results of running the scenario are discussed in this case study. The full script is included as an appendix to this case study, and it can also be downloaded from the IPAT-S web site. Readers who are interested in exploring and modifying the scenarios can download the script and the free IPAT-S software from http://www.kb-creative.net/IPAT_S.

[1]The term "Environmental Kuznets Curve" was coined by Seldon and Song (1994), following earlier papers by Grossman and Krueger (1992), Shafik and Bandyopadhyay (1992) and Panayotou (1993). The literature on the Environmental Kuznets Curve (EKC) is reviewed and critiqued in Stern, Common and Barbier (1996) and Rothman and de Bruyn (1998), the latter as an introduction to a special issue of *Ecological Economics* on the EKC. Tidsdell (2001) and Rothman (1998) offer critiques of what has become the conventional EKC approach.

Note that for some the EKC hypothesis is a source of hope while for others it is a source of concern. For example, in the academic literature, Beckerman (1992) claims that "...in the end the best – and probably the only – way to attain a decent environment in most countries is to become rich," while in the popular literature, Pipes (2002) claims that "...more and more environmentalists are coming to acknowledge that economic growth is the main prerequisite for an improving environment..." In contrast, Munasinghe (1999), asks if "environmental degradation is an inevitable consequence of economic growth," and suggests that countries should "tunnel through" the EKC, rather than passing over it.

Functional Forms for the Environmental Kuznets Curve

The Environmental Kuznets Curve hypothesis is easily formulated in an IPAT framework.[2] In IPAT, an environmental impact *I* is expressed as a product of factors – population, *P*, "affluence" (GDP per capita), *A* and "technology," *T*:

$$I = P \times A \times T \,.$$

In this equation, because *P* multiplied by *A* is just GDP, the technology factor *T* must be the ratio of the environmental impact to GDP. The Environmental Kuznets Curve hypothesis is a statement about *T*. It says that *T* is a function of *A* that increases at small values of *A* and declines at high values of *A*. Any functional form for an environmental Kuznets curve must reflect this.

Regression Equations

In empirical studies of the Environmental Kuznets Curve hypothesis, a particular environmental impact (or an impact indicator) is chosen. For example, as an indirect indicator of environmental impacts from sulfur emissions, total SO_x emissions may be chosen to represent environmental impact *I*. Then the technology factor *T* is estimated by dividing *I* by GDP, and a regression is performed on a quadratic functional form:[3]

$$\ln\left(T(A)\right) = a + b\ln(A) + c\ln^2(A) \,.$$

If *b* is positive and significant, and *c* is negative and significant, then *T* must increase at low *A* and decline at high *A* – in this case the pollutant in question exhibits the features of an environmental Kuznets curve.

As presented here, in logarithmic form, the regression formula can be used for scenario exercises. In principle it can be applied across a full range of values for *A*.[4] However, it exhibits a strongly income-dependent elasticity of environmental impact. That is, the percent change in *T* with each percent change in *A* varies significantly across the full range of incomes. Below, a formulation is proposed that asymptotically approaches a constant-elasticity function at low and high values of *A*.

An Alternative Form for the Environmental Kuznets Curve

For scenario exercises, where the goal of the modeling exercise is to explore the implications of a scenario narrative in a variety of circumstances, a formulation is needed that will work for a wide range of values of *A*. Also, it must be relatively simple, with a small number of free parameters. The regression formula above fits these criteria. An alternative form is proposed here, which in addition asymptotically approaches a constant-elasticity function at low and high values of *A*. The form proposed in this case study is the

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[2]Outside of the academic literature, the Environmental Kuznets Curve idea is sometimes presented as an alternative to the IPAT framework, or in opposition to it. This seems to result from a mistaken belief that the factors *P*, *A* and *T* in the IPAT formula can only increase. However, they can either increase or decrease. In the case of the Environmental Kuznets Curve, the *T* factor does both.

[3]In this formula, (the log of) impact per dollar GDP is regressed against (the log of) GDP per capita. Alternatively, impact per capita may be used or, more rarely, the total impact.

[4]Some studies have not used a logarithmic form, and these are inappropriate for scenario exercises. The reason is that the regressions cannot be true for all values of *A*. If *A* is large enough, then eventually *T* will be negative, if the regression equation is literally true – but this does not make sense. At any level of consumption, there must be some impact on the environment, either through resource extraction or by exploiting the waste-processing capability of the natural environment, so *T* should remain positive.

following one:[5]

$$T(A) = \left(1 + \frac{\varepsilon_{\text{high}}}{\varepsilon_{\text{low}}}\right) \cdot \frac{\varepsilon_{\text{low}}\, T_{\text{max}} \left(A/A_{\text{max}}\right)^{\varepsilon_{\text{low}}}}{\varepsilon_{\text{high}} + \varepsilon_{\text{low}} \left(A/A_{\text{max}}\right)^{\varepsilon_{\text{low}} + \varepsilon_{\text{high}}}}$$

While this may appear complicated, it has a simple behavior:

- When A is at A_{max}, T is equal to T_{max}. At any other value of A, T will be less than T_{max}.
- When A is much smaller than A_{max}, T is approximately equal to

$$T(A) \approx \left(1 + \frac{\varepsilon_{\text{low}}}{\varepsilon_{\text{high}}}\right) \cdot T_{\text{max}} \cdot \left(\frac{A}{A_{\text{max}}}\right)^{\varepsilon_{\text{low}}}, \qquad A \text{ much less than } A_{\text{max}},$$

while when A is much larger than A_{max}, T is approximately equal to

$$T(A) \approx \left(1 + \frac{\varepsilon_{\text{high}}}{\varepsilon_{\text{low}}}\right) \cdot T_{\text{max}} \cdot \left(\frac{A}{A_{\text{max}}}\right)^{-\varepsilon_{\text{high}}}, \qquad A \text{ much larger than } A_{\text{max}}.$$

This means that at low incomes, T increases with an income elasticity of ε_{low}, while at high incomes, T decreases with an income elasticity of $-\varepsilon_{\text{high}}$. This behavior has a simple interpretation. As with any elasticity, it means that a 1% increase in income leads to an $\varepsilon_{\text{low}}\,\%$ increase in T at low incomes, and a $-\varepsilon_{\text{high}}\,\%$ decrease in T at high incomes.

To summarize, with this formulation, there are four parameters, each with a straightforward interpretation:

- T_{max}, the maximum value for T.
- A_{max}, the income where T reaches T_{max}.
- ε_{low}, the income elasticity of T at low incomes.
- $-\varepsilon_{\text{high}}$, the income elasticity of T at high incomes.

The connection between the usual regression curve and the functional form proposed here is as follows. If the full curve behaves like the functional form proposed here, then in the region of the peak it behaves like the regression curve. In that region, the regression curve can be used as an approximation, with

[5] This formula was inspired by the work of Common (1995), as described in Perman, Ma and McGilvray (1996). Common had T reach a constant level at sufficiently high income. However, it is not necessary to make this assumption – T can decrease indefinitely, as long as it does not reach a value of zero.

$$a = \ln(T_{\max}) + \frac{1}{2}\,\varepsilon_{\text{low}}\,\varepsilon_{\text{high}} \cdot \ln^2 A_{\max}$$
$$b = \varepsilon_{\text{low}}\,\varepsilon_{\text{high}} \cdot \ln A_{\max}$$
$$c = -\frac{1}{2}\,\varepsilon_{\text{low}}\,\varepsilon_{\text{high}}$$

Note that matching the parameters between the regression formula and the formulation proposed here does not uniquely determine the elasticities ε_{low} and $\varepsilon_{\text{high}}$. Instead, it determines their product. This indeterminacy arises because the regression formula has three parameters, while the formula proposed here has four. This can be seen as an advantage of the formulation proposed in this case study. The regression formula probes only part of the Environmental Kuznets Curve. It cannot be reliably and uniquely extrapolated to values outside of the range where it has been tested. The present formulation is a reminder of this, and allows a scenario analyst to explore alternative assumptions, in that the behavior of the function at very high and low incomes is not uniquely determined by how the curve looks near the peak.

There is a further theoretical advantage to the formulation offered in this case study. In general, a constant income elasticity function is to be expected when there is no income *scale* that marks a change in economic or environmental regime. In the Environmental Kuznets Curve approach, there is an income scale, set by $A_{\max}$. Very far from $A_{\max}$, however, at high and low income, the economy, and people's behavior should be indifferent to the transition at $A_{\max}$, so it is reasonable that at very high and low incomes the curve should asymptotically approach a constant-elasticity function.

An Example Scenario

For purposes of illustration, an example scenario is presented below using the functional form for the Environmental Kuznets Curve presented in this case study. The scenario has been implemented in the IPAT-S scenario scripting language. The IPAT-S interpreter can be downloaded at no charge, and the IPAT-S script used for these scenarios is printed in its entirety in the appendix. Readers are encouraged to investigate their own assumptions by downloading the IPAT-S software, entering the script and modifying it as they desire.

Scenario Overview
In the scenario, the world is split into a "High Income" and a "Low Income" region, roughly corresponding to the UN Population Division's "More Developed" and "Less Developed" country groupings. The income growth rate of the High Income region is set at 1.5% per year, while income in the Low Income region converges toward that of the High Income region.

The Environmental Kuznets Curve hypothesis is sometimes promoted by market optimists as a cure for potential environmental ills, and in that spirit the entire scenario has a market-optimistic slant. Nothing hinders the Low Income region from converging in average income toward the High Income region, and populations follow the UN low projection, rather than the more commonly-assumed medium projection.

The parameters for the Environmental Kuznets Curve itself are:

- $T_{\max}$ = 1000 (arbitrary units)
- $A_{\max}$ = $3500 (in 2000 PPP-weighted US dollars)
- ε_{low} = 1.0

- ε_{high} = 1.0

Aside from the arbitrary value for T_{max}, these figures are based on the regression formula of Panayotou (1993) for SO_2 emissions, as reported in Stern, Common and Barbier (1996). Using 1985 dollars at nominal exchange rates (rather than PPP, as used here), Panayotou's values for *b* and *c* in the regression are 7.31 and -0.51, respectively. (The value for *a* is unimportant, since T_{max} is arbitrary.) Matching this empirical curve to the functional form proposed here, this implies that ε_{low} multiplied by ε_{high} is 1.02, or about equal to one, while A_{max} is about $1300 in 1985 dollars at nominal exchange rates.

For the scenario presented in this case study, the value for A_{max} must be adjusted to give 2000 PPP-weighted US dollars. Data from the Penn World Table mark 5.6a verify the common observation that values of GDP/capita using PPP are generally larger than GDP/capita at market exchange rates. Moreover, incomes at PPP rise with income at market exchange rates roughly to the 0.75 power. Using this observation to adjust Panayotou's maximum from nominal to PPP exchange rates and further assuming an average inflation rate of 2.0% between 1985 and 2000 gives a value for A_{max} of about $3500. (This is an unsophisticated adjustment. Suggestions for improvement on this procedure would be welcome.)

As discussed above, the values for the elasticities cannot be determined directly from the regression parameters. Instead, the product is determined. For this case study, it is assumed that the elasticities are the same (aside from a sign) above and below the peak. This keeps the curve reasonably close to the regression formula across a wide range of incomes. Specifically, each 1.0% rise in income leads to a 1.0% rise in impact per dollar at very low incomes and to a 1.0% decline in impact per dollar at very high incomes. Note that the scenario outcome is quite responsive to changes in this assumption. Readers interested in exploring alternative options can download the free IPAT-S software and modify the script provided in the appendix.

The scenario extends from 2000 to 2050 with figures reported every 10 years.

Scenario Results

Environmental impact in the scenario, broken out by region, is shown below in Figure 1. In spite of an eventual decline in impact in the High Income region, total impacts increase nearly 90% between 2000 and 2040, rising to very high levels in the Low Income region, and declining slightly after 2040. The situation may be improving in impacts per GDP as incomes rise, but the rapid growth of GDP defers the benefits several decades in the future.

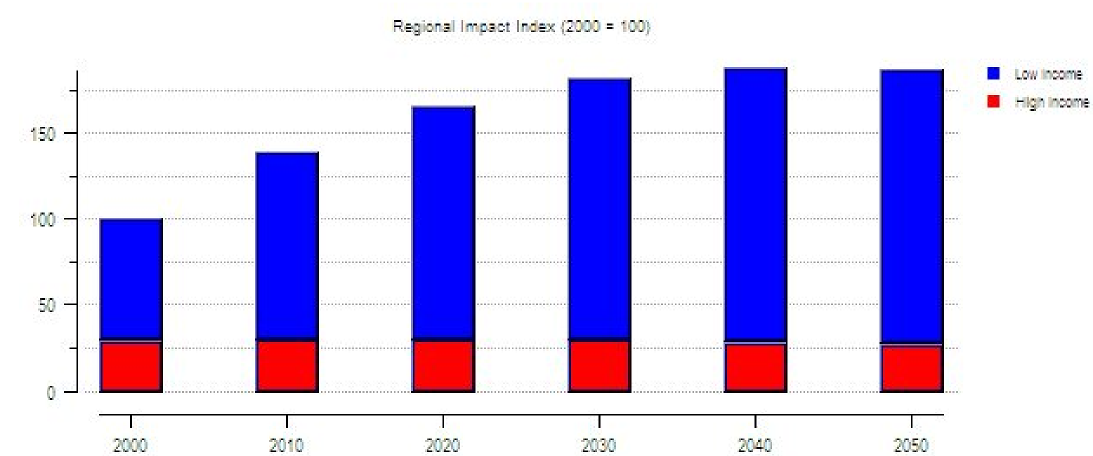

Figure 1. Environmental impact by region.

A similar picture can be seen when examining impact against gross world product (GWP) per capita, as shown in Figure 2. GWP per capita – the average of the high and low income regions – rises substantially over the scenario, exceeding $30,000 dollars on average by the end of the scenario. Nevertheless, the impact remains high, as steep declines in impact intensity (see Figure 3) are offset by rising affluence.

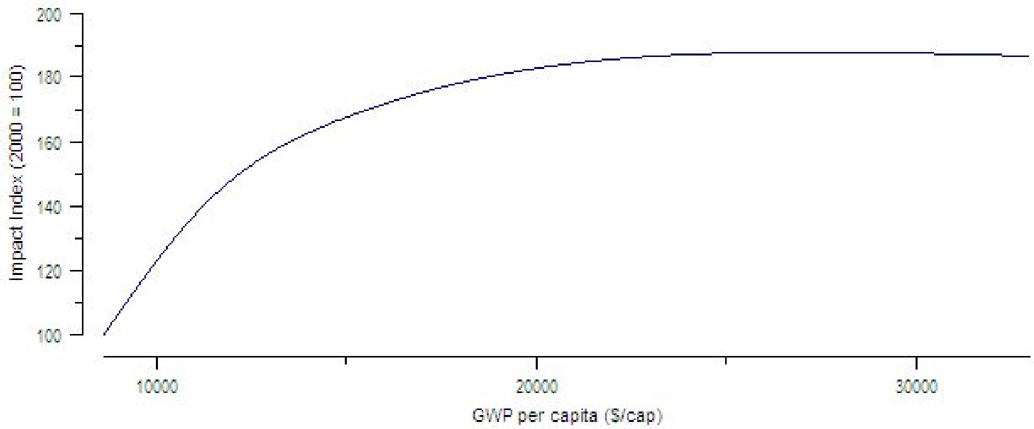

Figure 2. Environmental impact vs. GWP per capita.

Indeed, looking only at impact intensity, rising incomes make a large difference in the scenario, as shown in Figure 3. Note, however, that the peak intensity for the world is close to $10,000 – that is, nearly three times the peak for the individual regions. The reason for this is that average income is dominated by the High Income region, while emissions are increasingly dominated by the Low Income region as the scenario progresses.

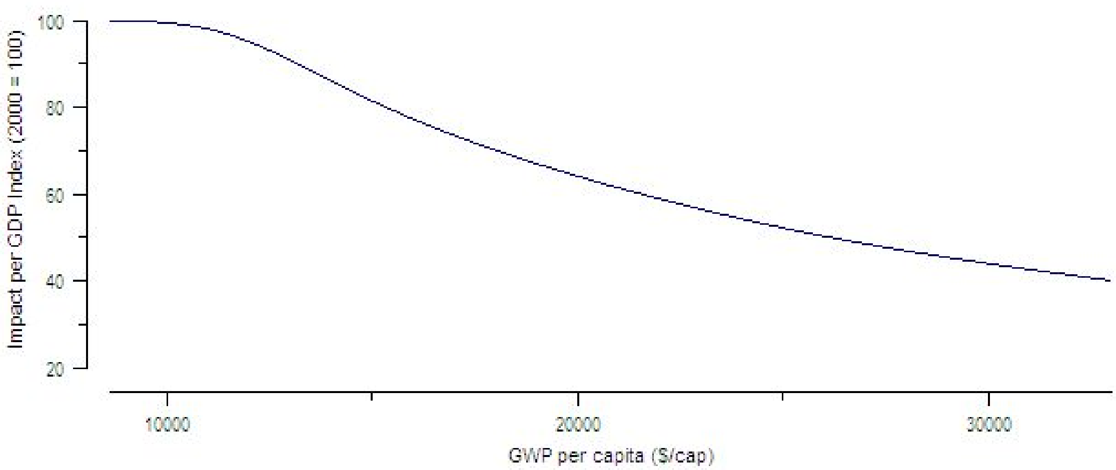

Figure 3. Environmental impact intensity vs. GWP per capita.

Conclusions
Having presented a scenario it is tempting to draw lessons from it, even though it was offered to illustrate the use of the proposed formulation of the Environmental Kuznets Curve. I will present the lessons that suggest themselves to me; feel free to draw your own conclusions, and feel free to explore the IPAT-S script on your own using the software from http://www.kb-creative.net/IPAT_S.

The Environmental Kuznets Curve is often invoked without looking at its implications explicitly. To the extent that it holds true of actual environmental impacts – and the evidence is mixed – it certainly adds weight to the already attractive idea of raising the incomes of low-income countries. However, it is no panacea. Rising affluence by itself, even if the Environmental Kuznets Curve holds, will not prevent environmental damage, and if it is relied on to the exclusion of regulatory efforts the damage could undermine the growth itself. In other words, there is no shortcut to *sustainable* development. It requires a simultaneous focus on economic growth, environmental management and (although not explored here) social justice.

That being said, this conclusion depends to some degree on the detailed assumptions made in the particular scenario presented here. Interested readers are invited to modify the assumptions of the scenario to explore alternative possibilities.

Finally, it is hoped that the formulation presented in this paper for the Environmental Kuznets Curve can be of use to scenario analysts. As discussed in the paper, it has theoretical and practical advantages over some alternative formulations.

References

Beckerman, W. “Economic Growth and the Environment: Whose Growth? Whose Environment?” *World Development* 20: 481-496, 1992.

Common, M. 1995. *Sustainability and Policy: Limits to Economics*. Cambridge University Press, Sydney.

Grossman, G.M. and A.B. Krueger. 1992. “Environmental Impacts of a North American Free Trade Agreement,” Woodrow Wilson School, Princeton, N.J.

Munasinghe, M. “Is Environmental Degradation an Inevitable Consequence of Economic Growth: Tunneling through the Environmental Kuznets Curve,” *Ecological Economics* 29: 89-109, 1999.

Panayotou, T. 1993. “Empirical Tests and Policy Analysis of Environmental Degradation at Different Stages of Economic Developmeent.” Working Paper, Technology and Environment Program, International Labour Office, Geneva.

Perman, R., Y. Ma and J. McGilvray. 1996. *Natural Resource and Environmental Economics*. Addison Wesley Longman Limited: London.

Pipes, S.C. “Environment’s Future Looking Less Gloomy,” *San Francisco Examiner*, April 26, 2002.

Rothman, D.S., “Environmental Kuznets Curves – Real Progress or Passing the Buck? A Case for Consumption-Based Approaches,” *Ecological Economics* 25: 177-194, 1998.

Rothman, D.S. and S.M. de Bruyn, “Probing into the Environmental Kuznets Curve Hypothesis,” *Ecological Economics* 25: 143-145, 1998.

Seldon, T. and D. Song, “Environmental Quality and Development: Is there a Kuznets Curve for Air Pollution Emissions?” *Journal of Environmental Economics and Management* 27: 147-162, 1994.

Shafik, N. and S. Bandyopadhyay. 1992. “Economic Growth and Environmental Quality: Time Series and

Cross-Country Evidence." Background paper for *World Development Report 1992*, World Bank, Washington, D.C.

Stern, D.I., M.S. Common and E.B. Barbier, "Economic Growth and Environmentl Degradation: The Environmental Kuznets Curve and Sustainable Development," *World Development* 24(7): 1151-1160, 1996.

Tidsdell, C., "Globalization and Sustainability: Environmental Kuznets Curve and the WTO," *Ecological Economics* 39: 185-196, 2001.

Appendix: IPAT-S Script

```
comment:
This sample script implements an environmental Kuznets curve.
The basic IPAT equation is used, but the technology factor "T"
varies with income following a Kuznets-like shape. The curve
has an "inverted-U" at low-to-moderate income, then has a long
tail. The income elasticities at low incomes and on the high-income
tail are parameters in the script (lowElast and -1 * highElast).

The script also features relative income convergence. The GDP per capita
growth rate for the high-income region is set as an exogenous
parameter, with other regions then converging towards the high-income
region at a rate convRate. The formula for convergence is similar to
the one in Barro's regression:

   d ln(y)/dt = r - k * ln(y/y_high) + ...

where all additional terms (...) are assumed to be zero. In the script,
the parameter r is highGR, and k is convRate. Because no factors are
assumed to hinder income convergence (the "..." in the equation), the
UN low population projection is used.
:comment

base year 2000
scenario years 2010 to 2050 by 10

# More regions can be added, as long as:
#  a) populations are specified
#  b) base-year data are specified
#  c) There is always a "High Income" region
dimension region 'Low Income' 'High Income'

var A{region} T{region}
summvar P{region} I{region}

# Income growth parameters
num highGR = <1.5%>
num convRate = <2.0%>

# Environmental Kuznets Curve (EKC) parameters
# Formula is:
#   T = (1 + highElast/lowElast) * Tmax * z^lowElast /
#         (highElast/lowElast + z^(lowElast + highElast))
# where z is A/Amax
num Tmax = 1000  # Absolute level doesn't matter
num Amax = <3500> # Income where EKC hits its maximum Tmax
num lowElast = <1.0>
num highElast = <1.0>

##
## Basic data
##
# UN Pop Prospects for "More Developed" and "Less Developed"
# countries (millions), low variant, 2002 revision
# http://esa.un.org/unpp
P{region = 'Low Income'} = 4877, 5478, 5952, 6268, 6385, 6325
P{region = 'High Income'} = 1193, 1211, 1207, 1187, 1144, 1083

# Average income per capita (PPP$/cap)
# From UNDP HDR 2002
# "High Income" and weighted average of "Middle and Low Income"
#    for year 2000, in PPP US$.
A.0{region = 'Low Income'} = 3970
A.0{region = 'High Income'} = 27640

##
## Income growth
##
# Convergence calculation
var z{region}
:: ln0(A/A{region = 'High Income'}) -> z
:: >> gr(-convRate) -> z

# Apply growth rate
:: exp(z) >> gr(highGR) -> A
```

```
##
## Technology factor, using environmental Kuznets curve
##
# Recycle the intermediate variable z
:: A/Amax -> z
:: (1 + highElast/lowElast) * Tmax * z^lowElast / \
      (highElast/lowElast + z^(lowElast + highElast)) -> T

##
## The IPAT equation
##
:: P * A * T -> I

##
## Report results
##
summvar totGDP totPop
summarize P * A as totGDP
summarize P as totPop
report totGDP/totPop as "GWP per capita ($/cap)"

summvar Itot
summarize I as Itot

report 100 * Itot/Itot.0 as "Impact Index (2000 = 100)"
report 100 * (Itot/totGDP)/(Itot/totGDP).0 as \
             "Impact per GDP Index (2000 = 100)"

report A as "GDP per capita ($/cap)"
report 100 * I/Itot.0 as "Regional Impact Index (2000 = 100)"
```