Institute for
New Economic Thinking

To Fight Climate Change,

Save Energy and Reduce Inequality

The IPCC was correct in emphasizing the need for early mitigation, but their analysis of possible growth trajectories appears to be faulty.

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We began work on climate change almost 15 years ago, supported since 2012 by INET. Three main themes – historical linkages between increases in energy and labor productivity levels, analysis of economic growth from the standpoint of effective demand to bring employment and distribution into the picture, and comparisons with orthodox narratives – have been at the focus throughout. Publication of our paper in *Nature Climate Change* (hereafter: *NCC*) provides an opportunity to review this work.

How have energy productivity and labor productivity tracked over time? Energy productivity, or the output/energy ratio, has grown historically at close to the same rate as the output/labor ratio or labor productivity. The International Panel on Climate change (IPCC) does not seem to have taken implications of this observation on board.

At the same time, a strong case can be made that early mitigation of greenhouse gas emissions will be essential if a catastrophic output and employment crash is to be avoided, a point emphasized by the IPCC.

Most of the analysis is undertaken with demand driven economic growth models which allow the study of how unemployment and income distribution shift over time, though many of the same results come through in a mainstream setting which presupposes full employment and demonic optimization by economic "agents."

In a bit more detail, the discussion starts with the historical significance of the increasing use of fossil fuel energy in step with the growth of labor productivity. This linkage creates greater emissions of CO_2 which feedback negatively on growth and would crash the economy in a relatively short period of time (a few hundred years). Prompt mitigation becomes essential if irreversible climate change and an economic crash are to be avoided. A demand-driven model of economic growth is used to illustrate why front-loading of mitigation is essential. The IPCC has been prescient in advocating early mitigation, but it perhaps overestimates the possibilities for breaking away from the close relationship between use of fossil fuel energy sources and growth of output per capita.

Next, we take up the welfare economics of climate change, including procedures to estimate the social cost of carbon emission, and conclude with the implications of the *NCC* paper. Our research program has been coherent in concentrating on distribution, employment, and growth under global warming.

Historical linkage between energy productivity and labor productivity

The first practical use of fossil fuel (coal) energy for raising productivity was the 1712 Newcomen engine for pumping water from mines – more than 300 years ago. Boulton and Watt followed in 1775, and applications of steam power grew rapidly – including railroads on steel tracks around 1825, blast furnaces operating in parallel, and so on. In 1865 the economist William Jevons suggested that growth of energy productivity would be so rapid as to cut prices and induce more demand (the issue is discussed today under the title "rebound effect" and remains controversial).

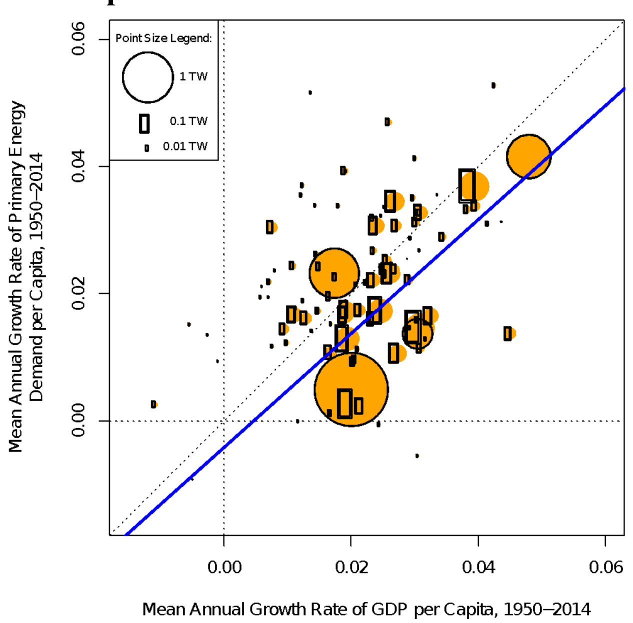
Maybe the clearest example is semi-literary. In a famous passage describing the mid-1880s in *Anna Karenina* the landowner Konstantin Levin accompanies his peasants to mow hay with a scythe, learning to use the tool. Seventy-five years later the teenage Mikhail Gorbachev drove a combine in the North Caucasus, doing much more work using the energy embodied in the machine and the fuel.

As discussed in Taylor (2008) and the *NCC* paper an illustration in terms of algebra is straightforward. Let X stand for output, L employment, E energy use, and $q = \frac{E}{L}$. With $\varepsilon = \frac{X}{E}$ as energy productivity and $\xi = \frac{X}{L}$ as labor productivity we get

$$\varepsilon = \frac{\xi}{q}.$$

That is, energy productivity is the ratio of labor productivity to the energy/labor ratio. The data in our *NCC* paper suggest strongly that q rises in direct proportion to ξ, especially in the mid-range of energy use across countries, consistent with the historical record. Complementary cross-section evidence using growth rates and building on Taylor (2008) is presented in Semieniuk (2018), which highlights the constraints that labor productivity growth puts on the growth in energy productivity by raising the energy/labor ratio (Figure 1). A country's energy demand is indicated by the size of its marker (inset at upper left in diagram).

Figure 1: Each point is a country's growth rate of labor productivity (x-axis) and the energy/labor ratio (y-axis) averaged over 1950-2014. The blue line is the best linear fit for the sample and the size of the dots is scaled to energy use.



Front loading

The next topic is modeling economic growth with this energy-growth relation built in, to serve as a tool for "top-down" analysis of future prospects (Rezai, Taylor, and Foley, 2018). Our model's behavior is driven by forces of demand, which allow discussion of employment and distribution as opposed to popular optimal growth models, which presuppose full employment of labor and capital. The key conclusion, consistent with IPCC recommendations, is to begin greenhouse gas mitigation early.

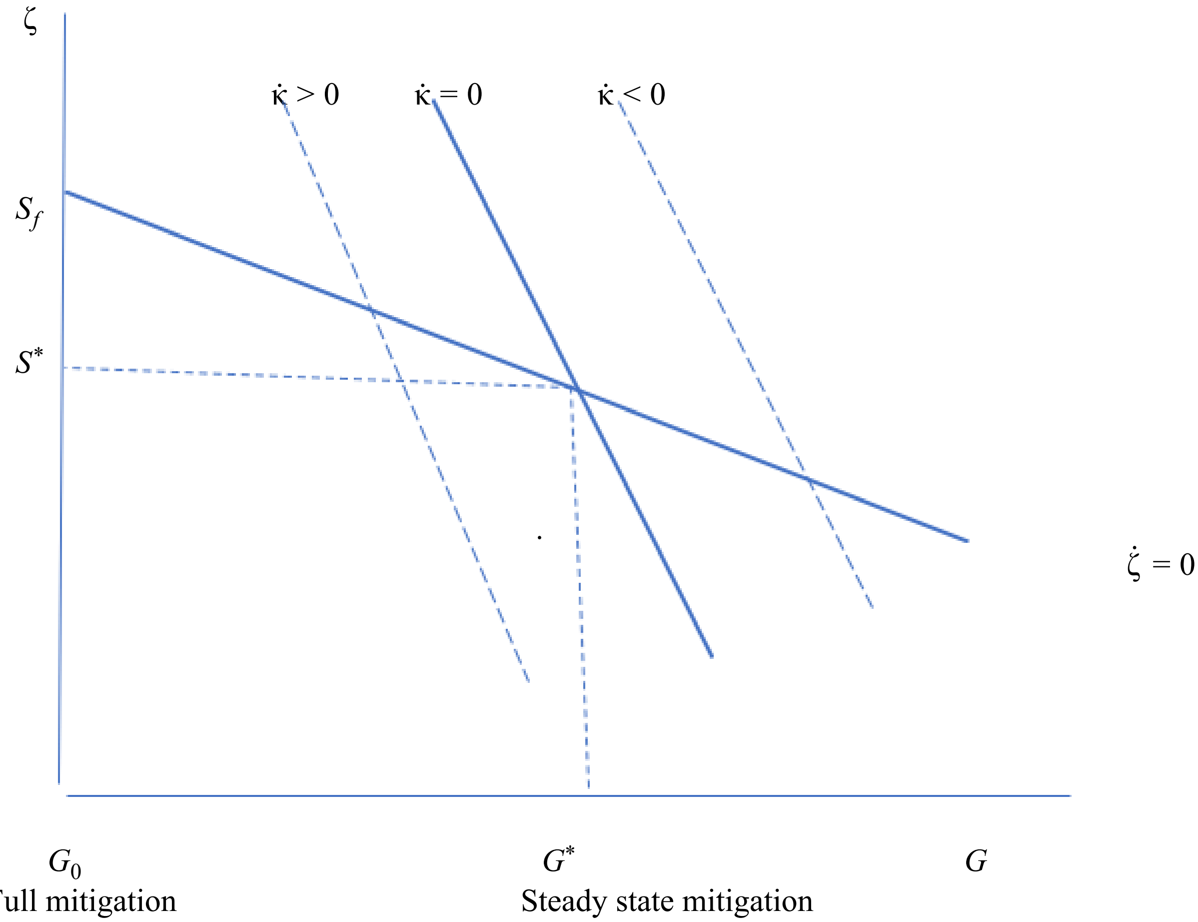
Three dynamic variables described by differential equations converge (over an infinite time horizon) to a "steady state" in which the ratio of any variable's change to its level is the same as all the others – all grow at the same exponential rate. If N is population and K capital (accumulated real investment), then at a steady state $\kappa = \frac{K}{N}$ is constant so both K and N increase at the same rate.

Along the transition to the steady state the ratio conditions need not be satisfied – demand drives the system (Taylor, Foley, and Rezai, 2019). The goal here is to walk through our model, but some basic growth accounting is necessary to describe it. One complication is that in a demand-driven system, changes in output and/or employment must be taken into account, adding an equation but making model results more plausible.

An increase in κ ($\dot{\kappa} = \frac{d\kappa}{dt}$) depends positively on investment ($g = \frac{I}{K)}$, and negatively on the stock of atmospheric $CO_{2,}$ (G, due to excess depreciation – an example would be a Category V hurricane hitting the Houston Ship Channel), the usual rate of depreciation and the rate of population growth (n). In standard notation the *growth rate* of κ is $\hat{\kappa} = \frac{\dot{\kappa}}{\kappa}$.

Labor productivity growth $\hat{\xi}$ also affects employment. It is assumed to respond positively to the growth rate of κ and to the employment ratio $\lambda = \frac{L}{N}$ (in the economic growth literature such behavior is said to come from "Kaldor-Verdoorn" and "induced innovation" effects respectively). An auxiliary variable $\zeta = \frac{\kappa}{\xi} = \frac{\lambda}{u}$ (with output X and $u = \frac{X}{K}$ as "capital utilization") is helpful in sorting out the dynamics. A positive value of $\dot{\zeta}$ signals that there is job creation due to increases in the capital/employment ratio ($\hat{K} - \hat{L}$) and/or output/population ratio ($\hat{X} - \hat{N}$). We assume that ζ increases with

Figure 2: The heavy lines are nullclines for κ and ζ, with a steady state at point (G^*, S^*). Contour lines for $\dot{\kappa}$ as a function of G and ζ are lightly shaded, with lower levels of $\dot{\kappa}$ along contours further to the right.



investment and decreases with G, normal depreciation, population growth, capital utilization, and the level of ζ itself (signaling stable dynamics).

There are conditions for $\dot{\kappa}$ and $\dot{\zeta}$ to equal zero. Both are implicit equations between G and ζ. In the jargon they are "nullclines" summarizing combinations of the state variables that hold $\dot{\kappa} = 0$ and $\dot{\zeta} = 0$. Points of intersection of nullclines define overall steady states, if they exist.

The effect of G on $\dot{\zeta}$ is negative due to increased depreciation and slower capital accumulation so the nullcline has a negative slope in the (G, ζ) plane, i.e. higher G would be associated with lower ζ. If ζ lies above the nullcline then it decreases (κ grows less rapidly than ξ) until $\dot{\zeta} = 0$.

The growth equation for κ is a relationship among three variables -- $\dot{\kappa}$, G, and ζ. It can be interpreted in at least two ways. If G is held constant, ζ is set by the steady state condition for ζ while $\dot{\kappa}$ is determined from its growth equation as a function of G and ζ. In Figure 2 different levels of $\dot{\kappa}$ are plotted along contour lines. Since capital stock growth is reduced by higher levels of both state variables, lines further toward the right correspond to lower, and eventually negative, levels of $\dot{\kappa}$.

A stable configuration of the nullclines is shown in the diagram. In the growth equation for ζ, $\dot{\zeta}$ is not strongly affected by G so the nullcline has a shallow slope. In the growth equation for κ, G has a stronger negative impact than ζ on $\dot{\kappa}$ so the contour lines are relatively steep. Under such circumstances, a high level of G is associated with relatively low levels of ζ *and* $\dot{\kappa}$ along the nullcline for $\dot{\kappa}$. In other words, higher GHG concentration leads to slower growth in the long run. With a low ζ, productivity is high relative to capital implying that employment is low and the profit rate high.

The stock of atmospheric carbon is the third state variable. Carbon accumulates due to production related emissions and dissipates at a low exogenous rate. Emissions are determined by the size of the economy, *X*, its energy use per unit output (i.e. the inverse of energy productivity, $\varepsilon = \frac{X}{E}$ with E as energy use), and the carbon intensity of the energy used, χ. Falling effectiveness of mitigation expenditure in curbing production-related fossil fuel emissions can be captured by an increasing concave function . Mitigation control becomes less effective as the effort increases. There are also natural emissions which must enter the accounting.

This specification is at odds with the convention in many models of economic growth that there is continued exponential growth of G. At present it is around one-half percent per year and climate damage is already apparent. Meanwhile κ is increasing at around one or two percent per year. It is rising with greater population and capital, meaning that the growth rate $\hat{G}$ is going up. The Malthusian logic of exponential growth shows that with incomplete mitigation, more rapidly increasing climate damage must choke off economic expansion in order to allow for a stabilization of G, κ, and ζ at a zero growth “stationary state.”

By raising capital utilization u, higher labor productivity increases the demand for energy. For their policy implications to be relevant, discussions on limits to growth and proposals for “de-growth” must recognize the endogeneity of technological progress and how income is generated.

In the absence of ambitious climate policy, the economy may go through just *one* boom-and-bust cycle before a crash. In ecology, this behavior is known as predator-

Figure 3: Illustrative simulations of the demand-driven model of economic growth and climate change. Climate policy which limits peak warming to 2°C (black) or 1.3°C (green) permits the economy to continue its current pattern exponential growth with increasing levels of income and high levels of employment. Under BAU (red), the economy follows its current pattern for several decades while global mean temperature rapidly increases.

prey dynamics. Since output is prey with a slow recovery rate, the cycle is likely to be damped.

We simulated a parameterized model calibrated to the world economy to study the dynamics numerically. Atmospheric temperature (degrees Celsius) is used instead of CO_2 concentration to measure the impact of global warming. Population is assumed to rise from 7 to 9 billion at the end of the century, stabilizing at 10 billion. The exogenous component of labor productivity grows at 1% per year initially but falls over time.

Figure 3 presents the simulations of growth and climate change for different levels of mitigation. There are three scenarios plotted on each panel: (i) “BAU” (red, short-dashed) where no emission abatement takes place, (ii) “2°C target” (black, solid) has the share of unabated emissions falling 6% per year such that the temperature rise stays within 2°C, and (iii) “Emission Mitigation” (green, long-dashed) holds new emissions equal to zero from the start. The cost of the “2°C” scenario peaks at 3% of GDP at mid-century and falls thereafter. Full mitigation costs significantly more, starting at 6% of GDP initially and falling to 3% by the end of the century and 2% by 2150.

The economy grows at 3% per year initially in all scenarios but the trajectories quickly diverge. In the “BAU” run, rapid growth generates high net emissions which translate into rising global mean temperature, surpassing 4°C at the end of the century and stabilizing at 7°C in 300 years. As temperature rises and climate damages increase, the profit rate falls. Investment levels are insufficient to maintain aggregate demand and unemployment results.

After this boom-bust cycle, output is back to its current level after 200 years but due to increases in labor productivity, employment relative to population falls from 40% to 15%. With the profit share fairly stable, this shift implies significant redistribution for working households, creating a dual economy for reasons of climate change. Those lucky enough to find employment are paid almost three times the current wage rate, but the others rely on subsistence income or public transfers. Only in the very long run, as labor productivity falls in response to rampant unemployment, can employment levels recover. But then the same amount of income spreads across more workers, since the overall size of the economy is limited by the climate constraint.

Mitigation allows the economy to avoid stagnation. In the "2°C target" scenario, fiscal outlays are slowly ramped up. The full mitigation version does better at controlling warming, but at higher cost. Given the dynamics implicit in the growth equations for κ and G, an initial mitigation push is essential to control emissions

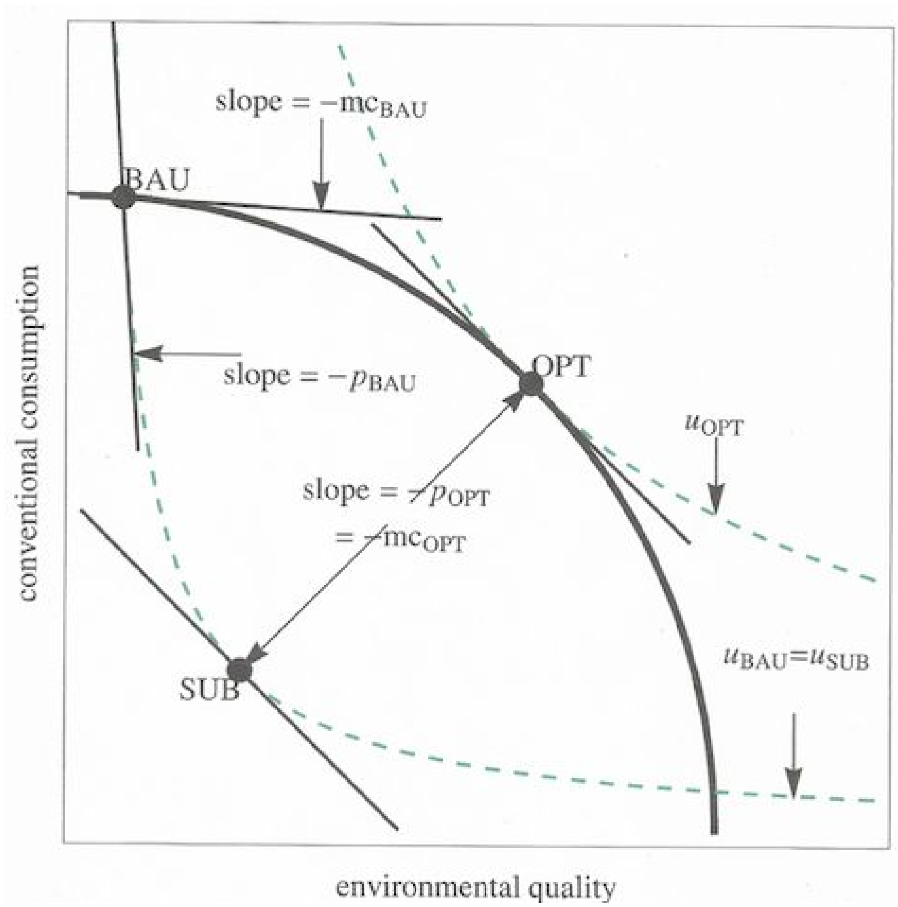
Either way, controlling CO_2 is essential to avoid a crisis only a few decades in the future. Environmental and social goals are not mutually exclusive so long as serious climate policy is implemented. If technological options for decarbonization are either unavailable or not deployed, output will be stabilized by a climate crash.

Welfare economics

For completeness and to complement the foregoing discussion, in Foley, Rezai, and Taylor (2013) we examined welfare implications of global warming using traditional tools. This world is populated with "agents," typically representative consumers who maximize utility and producers who minimize costs, so that informal description of behavior as above is ruled out.

The analysis is rather technical, but arrives at five main conclusions. The essence is in Figure 4. There is an "externality" in the sense that environmental quality is a public good. Any individual distrusts others and so is not willing to contribute to mitigation. If people were willing to pay, the social benefit from higher consumption would exceed the marginal cost. (Arguments along such lines are typical of this literature.)

Figure 4: Benefit-cost analysis of a climate externality



The diagram depicts a "corner solution" for a representative consumer and producer. The "first best" situation would be at point OPT with the consumer's indifference curve tangent to the production possibility curve. Welfare changes are indicated by slopes of the lines from the BAU point. In a move away from the corner, there is a low marginal cost (represented by the shallow slope of $-mc_{BAU}$) of expanding output and a high marginal benefit (welfare gain measured by the steep slope of $-p_{BAU}$) to the consumer.

The diagram does not provide helpful information about how to engineer these social changes (a "free lunch" is potentially available but we don't know how to get it because solving a collective goods problem is beyond the reach of the market by itself). This impossibility points to further observations.

Only at an efficient allocation of environmental quality and consumption is there an unambiguous measure of social marginal cost, i.e.at point OPT where the marginal benefit (slope of the dashed indifference curve) equals the marginal cost (the slope of the dashed curve at SUB).

One can set up an optimal growth model to try to estimate slopes of the benefit and cost curves illustrated in Figure 4. They must be conditional on a scenario that specifies a reference path of consumption and environmental quality, as well as on the consumption ‘‘felicity’’ or dynamic utility function and pure rate of time preference assumed for the typical individual and the technology described by particular production, damage, and mitigation functions. The discount rates at which the present value of costs and benefits must be calculated also depend on the reference path of consumption implied by each particular scenario.

The obvious question is how much a successful mitigation effort will cost. Comparably to the demand-driven model described above, we solved a model of optimal growth which exhibits the same cyclical behavior as energy and labor productivity grow at the same rate. Numerical simulations suggest that an ‘‘optimal’’ strategy for mitigation of climate change (with the social cost of mitigation equal to present discounted value of damages avoided) could be achieved by reallocating about 10% of current world investment (2.5% of world output) to mitigation of emissions. The social discount rate would decline as consumption growth slows. As is typical in dynamic optimization models without complicated constraints on timing, mitigation outlays as a share of output would be higher during early phases of the plan. (A ‘‘corollary’’ is that due to cheap labor, mitigation may be less costly in developing countries, so that it should be frontloaded there.)

On an optimal path, a plausible estimate of the marginal cost and benefit of mitigation is about \$200 per ton of carbon (\$55/tCO2). On a BAU path, the marginal cost would be about \$160/t of carbon (\$44/tCO2), but the marginal benefit would be about \$1500/t of carbon (\$410/tCO2).

Analysis of global warming

The *NCC* paper, especially Figure 1 therein, speaks for itself. Gregor Semieniuk put a tremendous amount of work into gathering and organizing IPCC projections of per capita income growth and the energy/labor ratio. For two decades the scenarios show *rising* income with a *stable* or even *declining* energy/labor ratio. Such projections are ahistorical (compare the *NCC* paper's Figure 1 with the discussion above) and do not take into account the real operational constraints on policy formation and technology implementation in countries with low and mid-level incomes

The IPCC was correct in emphasizing the need for early mitigation, but their analysis of possible growth trajectories appears to be faulty. One can hope that recent commitments by policymakers to decarbonize major economies by mid-century will show beneficial effects. Activist investors are pushing major emitters and fossil fuel firms to prepare strategic plans for forceful climate policies. These initiatives together with cost reduction within renewable energy sources provide reasons for cautious hope. But the window for action is close fast, so whether this hope is justified will become clear all too soon.

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