ATTACHMENT D.2. SCENARIOS USING THE NORDHAUS DICE AND RICE MODELS

William Nordhaus' DICE and RICE models are integrated assessment models used to study the economics of climate change over several-to-many decades at global and regional scales. Here we use them to gain insight into proposals for addressing climate change through intentional reductions in the growth of economic output. [1]

Introduction

Over the course of history social movements have periodically arisen that call for significant reductions in the time, effort and other resources committed to generating economic output. In the 1970s many young people in the developed West chose not to pursue high-consumption lifestyles and opted instead for lives of material simplicity. At the same time sympathetic economists and other scholars began advocating a transition to a steady-state economy, one in which goods and services were produced at some constant rate over time. More recently the "degrowth" or *décroissance* movement in Europe and elsewhere advocates a planned decrease in the rate of economic growth, including periods of absolute economic contraction, in developed countries worldwide, as a response to environmental challenges and as part of a larger movement towards a just, sustainable and more deeply flourishing world. [2]

We use the DICE and RICE models to assess two proposals of this sort. The first proposal calls for reductions in the supply of labor offered for the production of market goods and services. The second proposal calls for a planned accelerated decline in the rate of growth of total factor productivity. We call the first proposal **the Work-Life Balance** (WLB) proposal and the second the **Total Factor Productivity** (TFP) proposal.

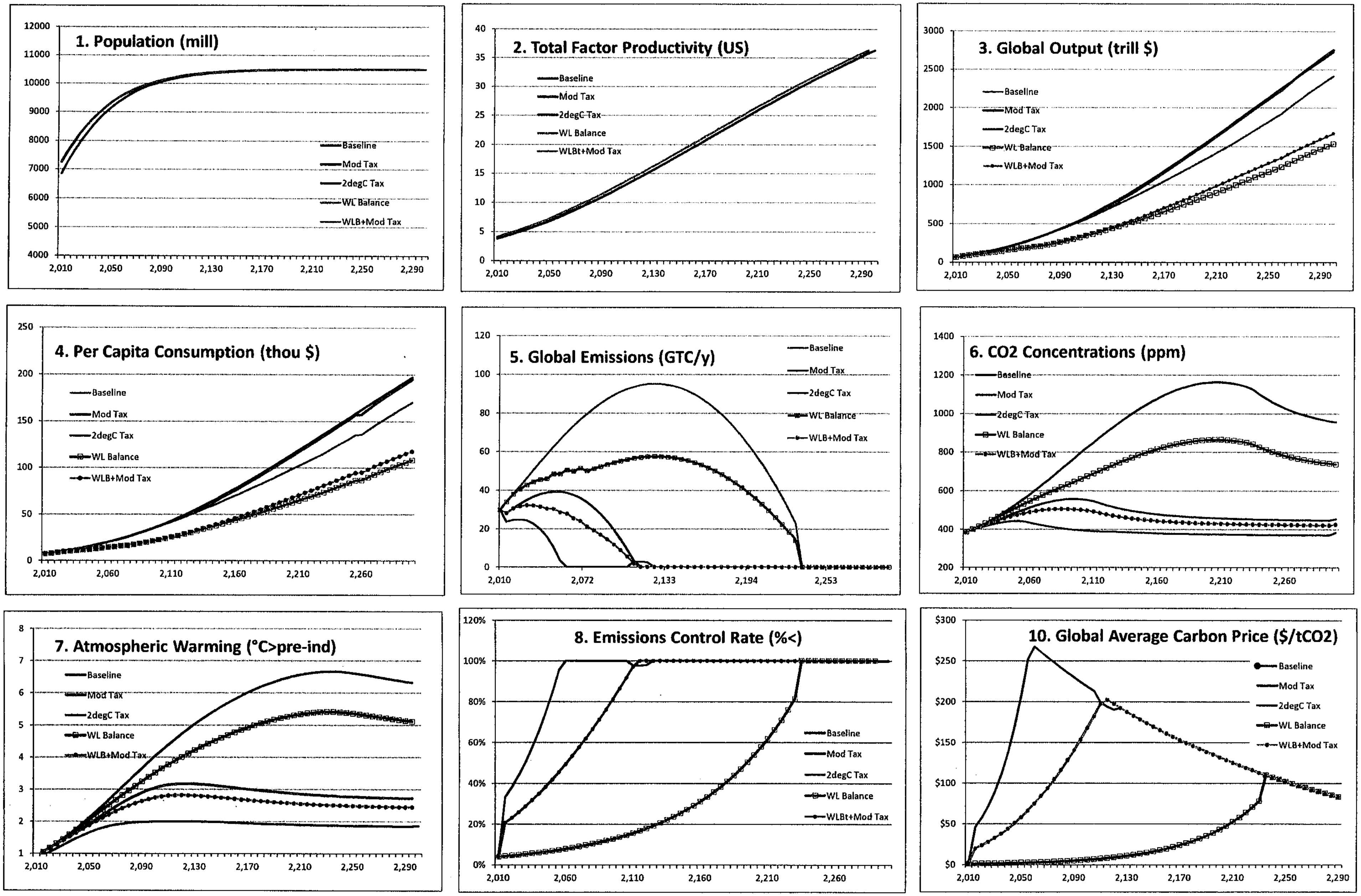
1. The Work-Life Balance proposal

In this proposal households worldwide reduce the supply of labor they offer for the production of market goods and services, while increasing the supply of labor available for non-market activities. They begin redirecting 5% of labor supply in 2025 from market to non-market activities, and increase this redirected share regularly over the following five decades. By 2075 households are supplying 40% less labor to the market than they had been supplying 50 years earlier. They hold to this new cultural norm indefinitely after 2075. We might visualize this scenario by imagining a household in which breadwinners reduce their paid work time from 5 to 3 days per week, or from 8 to 4.8 hours each day, or by any equivalent 40% reduction of paid work time.[3] [4] [5]

Display A shows three scenarios prepared by Nordhaus, together with two new scenarios incorporating the work-life balance proposal, all prepared using DICE:

a. The ***Baseline*** scenario shows the projected trajectory of economic growth and climate change if no new public sector policies are adopted and if households and firms respond in a conventional manner to market signals.

DISPLAY A. DICE MODEL RUNS SHOWING IMPACT OF CHANGES IN "WORK-LIFE BALANCE" PREFERENCES [$ = 2005 US]



b. The ***Moderate Carbon Tax*** (MCT) scenario shows the impacts of a moderate global carbon tax. The tax begins at ~ \$20/tCO2 in 2015, rises to ~ \$200/tCO2 by the first decades of the 22nd century, and then gradually declines.[6]

c. The ***2°C*** scenario shows the impact of a global carbon tax strong enough to keep anthropogenic climate change (ACC) below 2°C. The DICE model projects this to be a tax of ~ \$46/tCO2 beginning in 2015, rising to ~ \$260/tCO2 by 2060, and declining gradually afterward. [7]

d. The ***Work-Life Balance*** (WLB) scenario shows the impacts of a 40% reduction of market labor over the period 2025-2075, as described above.

e. The ***Work-Life Balance + Moderate Carbon Tax*** (WLB+MCT) scenario shows the results of adopting both the WLB and the MCT proposals as described above.

Results and comment

Under the Baseline scenario ACC peaks at 6.7°C in 2230, while under the WLB scenario it peaks in that same year at 5.4° C. This 19% reduction in peak ACC remains far above desired levels and is thus of little policy interest.

The MCT and 2°C scenarios each generate much greater reductions in ACC, but each comes with a challenge. The 2°C tax gets us the ACC outcome we desire, but may be unrealizable within the necessary time window. The more practicable MCT, however, has ACC peaking undesirably at 3.2°C in 2125.

What if we adopt *both* the MCT with WLB? Figure 7 suggests that the combined measures would be helpful but not dramatically so. ACC now peaks in 2125 at 2.8°C, 11% less than warming under the MCT alone, but still higher than most climate policy advocates would find acceptable.

Figures 3-7 make it clear that under the MCT+WLB scenario the *tax*, and not the WLB shift, is responsible for most of the ACC reduction. The tax drives fossil fuels from the market faster than moderation of consumption reduces demand for fossil fuels in the first place. It appears that those working to prevent ACC from exceeding 2.0°C would likely be better off redoubling their advocacy for steeper carbon taxes and similar policy tools than they would be embarking on a global crusade to engineer a half-century-long social, cultural and political transformation of the sort implied in the WLB proposal.

There is, however, a caveat. The displayed efficacy of the carbon tax depends heavily on assumptions built into the DICE model regarding *technology.* These include the baseline rate of change of total factor productivity, the rate of decline of carbon intensity, the rate of decline of CO2 abatement costs, and the existence and nature of a backstop technology, all projected over periods of at least two or three centuries. Under these assumptions the MCT drives us to a zero-emissions world by the first decades of the 22nd century, and the 2.0°C tax drives us there by 2060. If for any reason the technologies don't turn out to be as robust or as timely as they are assumed to be in the DICE model, the carbon pricing route becomes more expensive and the output reduction route relatively less so. [8] [9]

2. The Total Factor Productivity proposal

In this second proposal individuals, households and governments adopt lifeways and policies that slow the rate of growth of total factor productivity. This begins in 2045 and continues for 170 years until 2215, by which time annual TFP growth has declined to 0%. After that date the level of global output remains constant indefinitely. [10 11]

Display B shows the same three reference scenarios shown in Display A, a) *Baseline, b) Moderate Carbon Tax* and c) *2°C,* along with two new scenarios:

d. The ***Flat Total Factor Productivity*** *(Flat TFP)* scenario shows the results of measures taken to have the growth rate of total factor productivity decline more rapidly than it does under the Baseline scenario. World per capita consumption stabilizes in 2215 at ~ $50,000/yr, a seven-fold increase over 2010's per capita consumption of ~ $6,900/yr.

e. The ***Flat Total Factor Productivity + Moderate Carbon Tax*** *(Flat TFP+ Mod Tax)* scenario shows the results of adopting both the TFP scenario as just described and the MCT as described above.

Results and comment

In the Flat TFP scenario warming peaks at 5.7°C in 2225, about 15% below the Baseline peak of 6.7°C in 2230 but still far above the desired 2.0°C.

By itself MCT generates peak warming of 3.2°C in 2130. If the Flat TFP and MCT proposals are adopted together, warming peaks at 3.1°C in 2025, a barely discernable difference. Again, the carbon tax does the heavy-lifting.

The caveat noted earlier about assumptions in the DICE model regarding technology and technological innovation applies here as well. These could greatly influence the final trajectories.

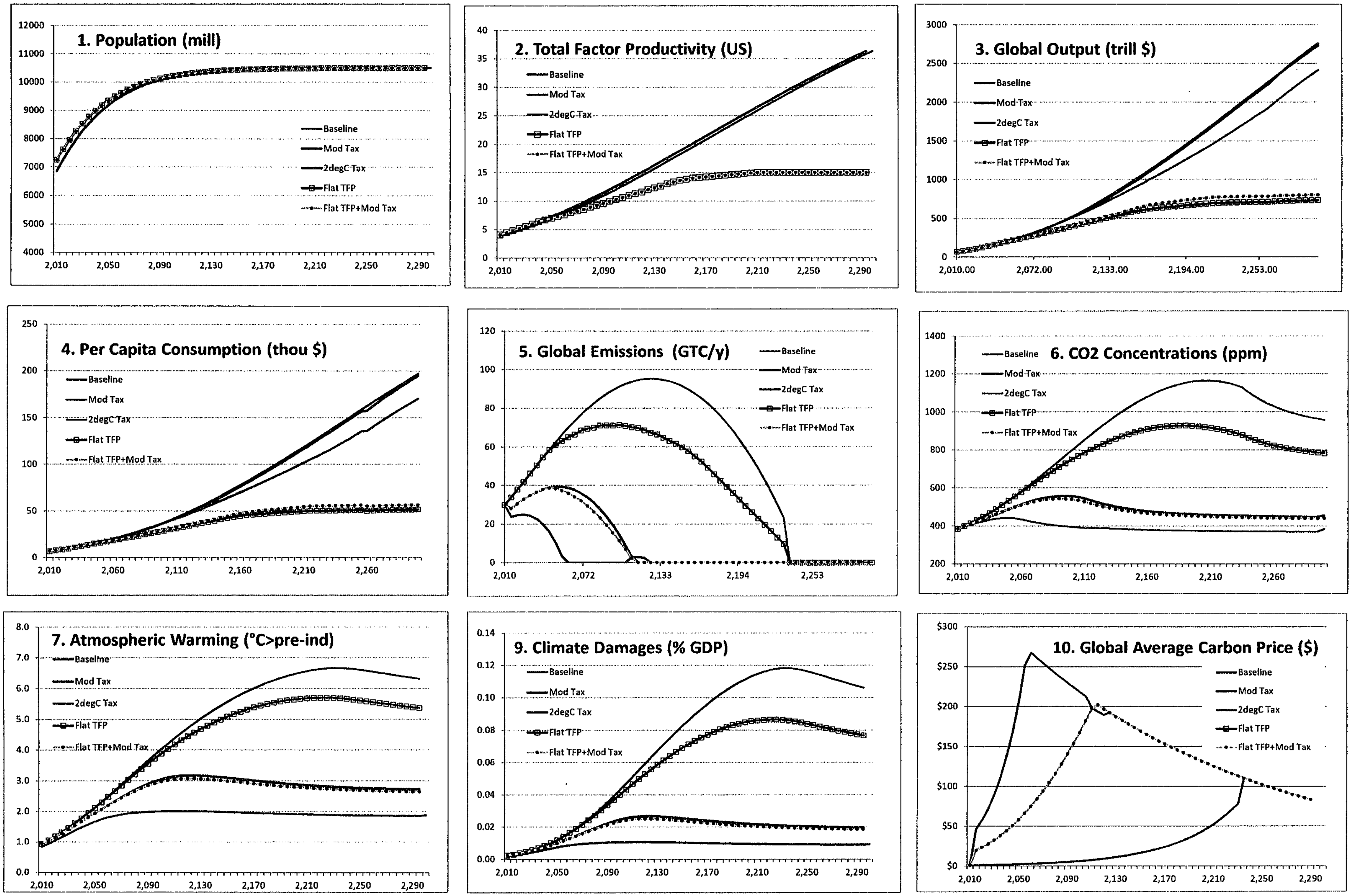
3. Scenarios Using the RICE Model

The RICE model goes beyond the single-polity DICE model and generates economic and climate trajectories for 12 geopolitical regions. This regionalization allows us to assess the impacts and interactions of climate change, economic growth and proposed policies among regions, and for any given region over time. **Display C** shows the reference Baseline and two tax policy scenarios included in Displays A and B. It also shows two scenarios incorporating limits on total factor productivity, similar but not identical to those just discussed using the DICE model. They are:

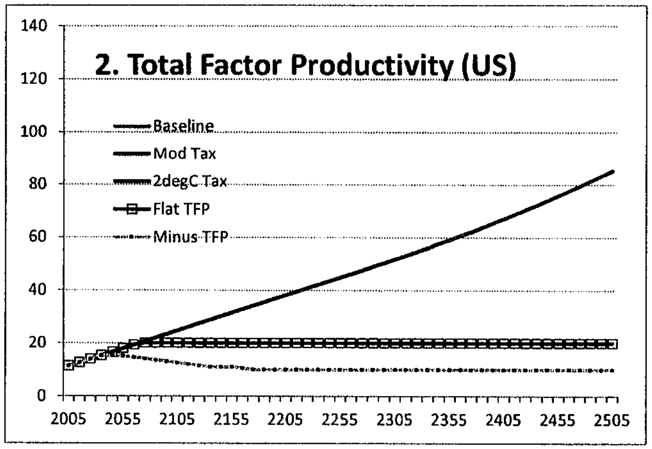
d. The **Flat Total Factor Productivity** (Flat TFP) growth scenario. In this scenario the growth of total factor productivity, and thus of output and consumption, ends in each region when per capita consumption in that region reaches levels of about $85,000/yr. After that date productivity, output and consumption remain constant indefinitely. Developed regions reach this steady-state point sooner than developing regions do. In the United States growth stabilizes in 2115, in Russia in 2185, in the Middle East in 2205, in Africa in 2255 and so on. Prior to its stabilization date, per capita consumption in each region grows at its RICE Baseline rate.

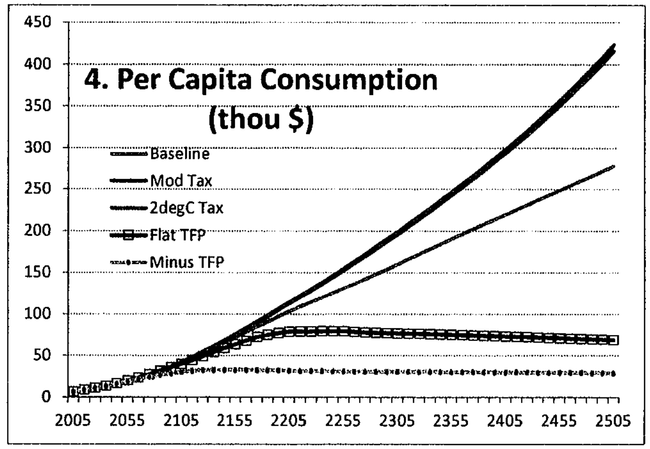
e. The **Negative Total Factor Productivity** (Minus-TFP) growth scenario. In this scenario total factor productively growth begins to slow in the more developed regions in the early 21st century, reaches zero and then goes negative in the mid-to-late 21st century with corresponding absolute contractions in output and consumption. It stabilizes at a new, lower level of output by the late-22nd century. For example, in the United States productivity begins to slow in 2025, peaks in 2045 with per capita consumption of about

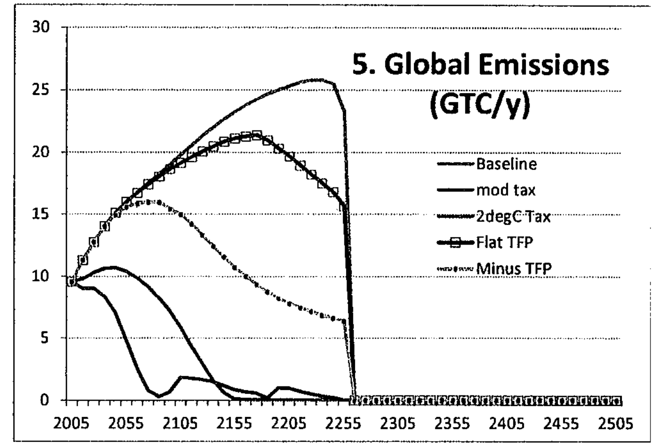
DISPLAY B. DICE MODEL RUNS SHOWING IMPACT OF AN INTENTIONAL DECLINE IN GROWTH OF TOTAL FACTOR PRODUCTIVTY [$ = 2005 US]

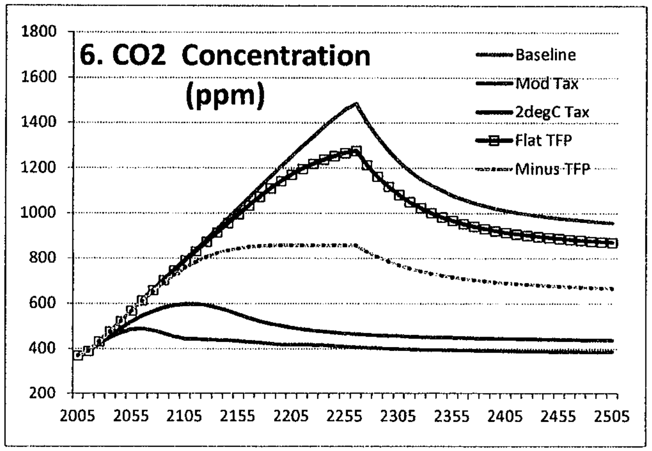


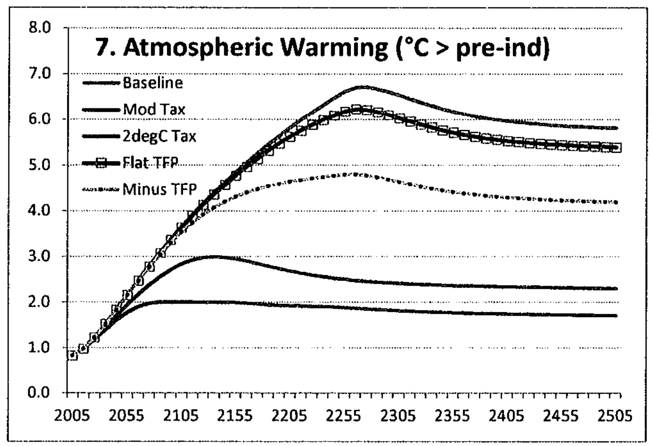
DISPLAY C. RICE MODEL RUNS INCLUDING CONSTRAINTS ON TOTAL FACTOR PRODUCTIVITY - [$ = 2005 US]

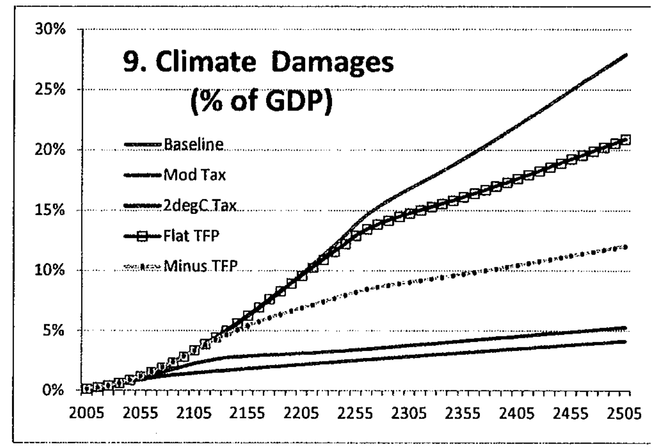


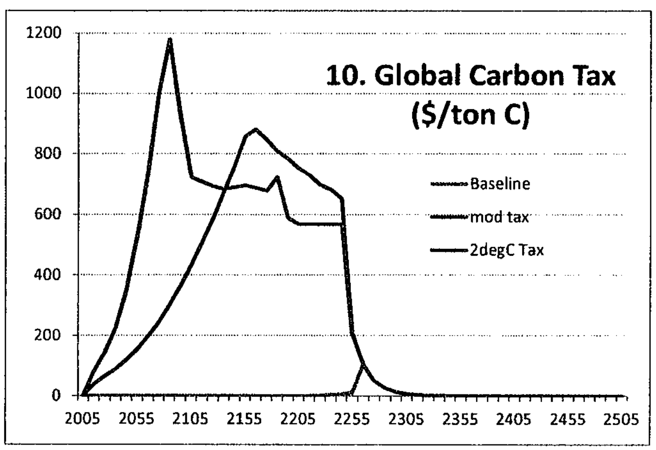


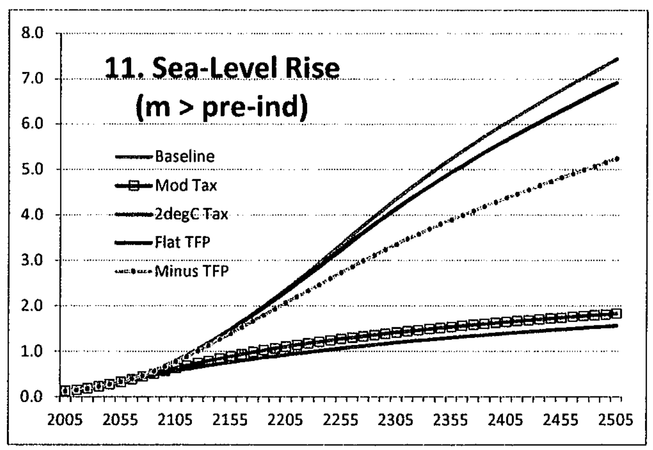












$58,000/yr) and begins to decline, finally stabilizing in 2185 with per capita consumption near $32,000/yr. Today's developing regions also show slowdowns in total factor productivity but they never go negative; rather, they converge with the formerly more developed regions in the late 22nd century and stabilize at that level of output. Africa, for example, begins in 2015 with per capita consumption of about $1,800, continues to grow at the RICE Baseline rates throughout the 21st century, and slows and stabilizes near $32,000 by 2165.

Results and comment

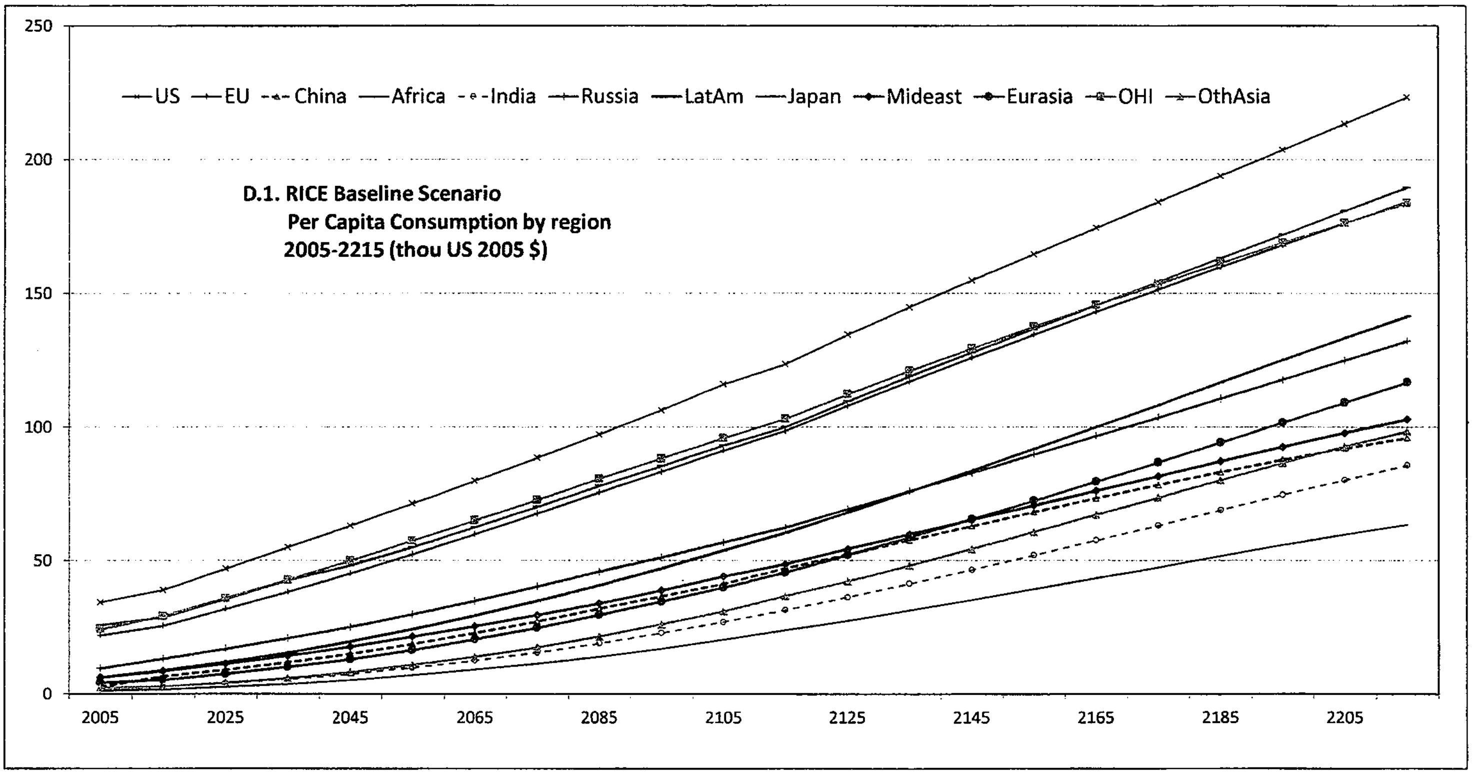
The unsurprising tentative major result is that the RICE model runs, like those of the DICE model, suggest that attempts to address climate change by directly reducing economic output are unlikely to be very effective, given our real-world starting points and assumed rates of change used in the models. Strong, and even moderate, carbon taxes are shown driving fossil fuels from the market faster than constraints on the growth of output will reduce demand for fossil fuels. As before, assumptions that ultimately reduce to assumptions about technology and technology innovation remain central.

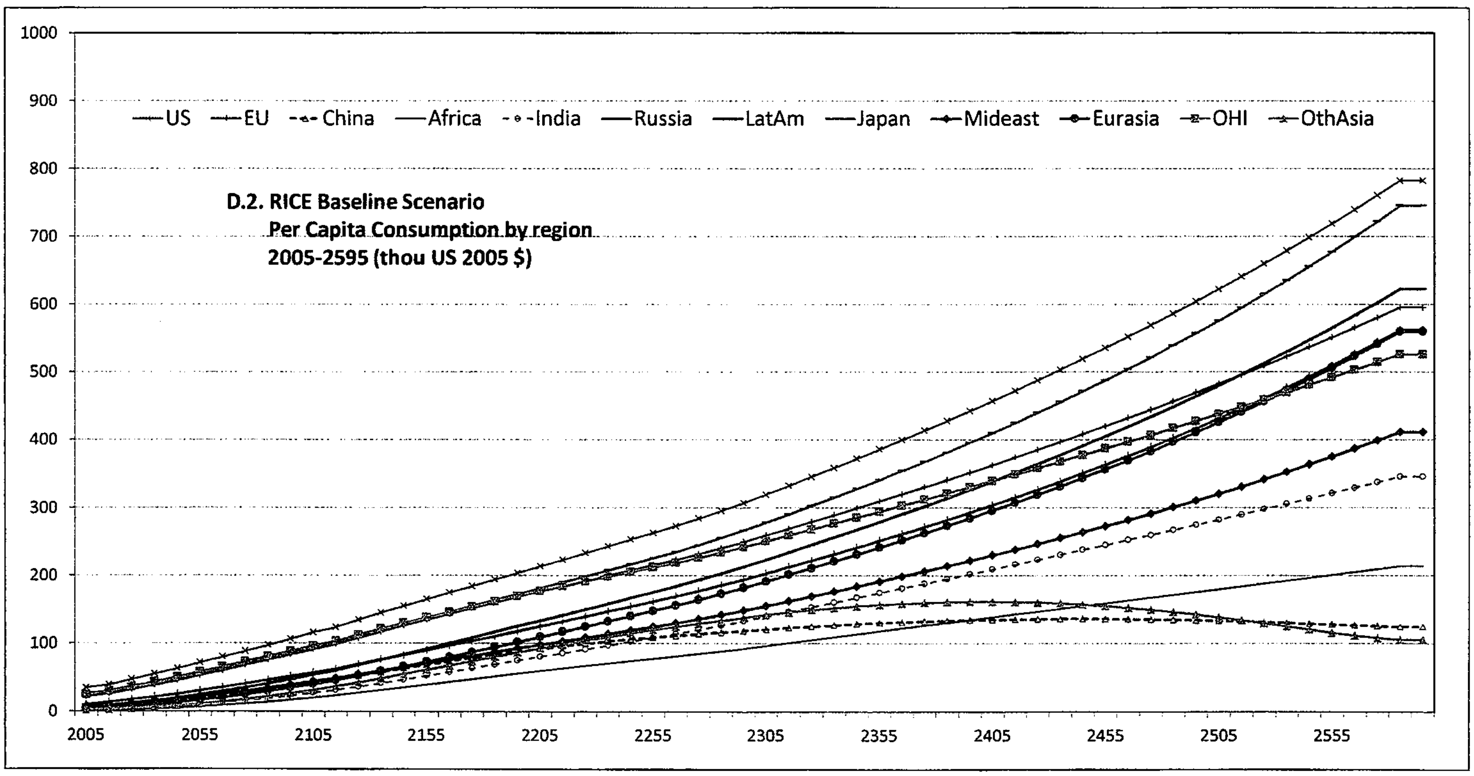
Regional Displays

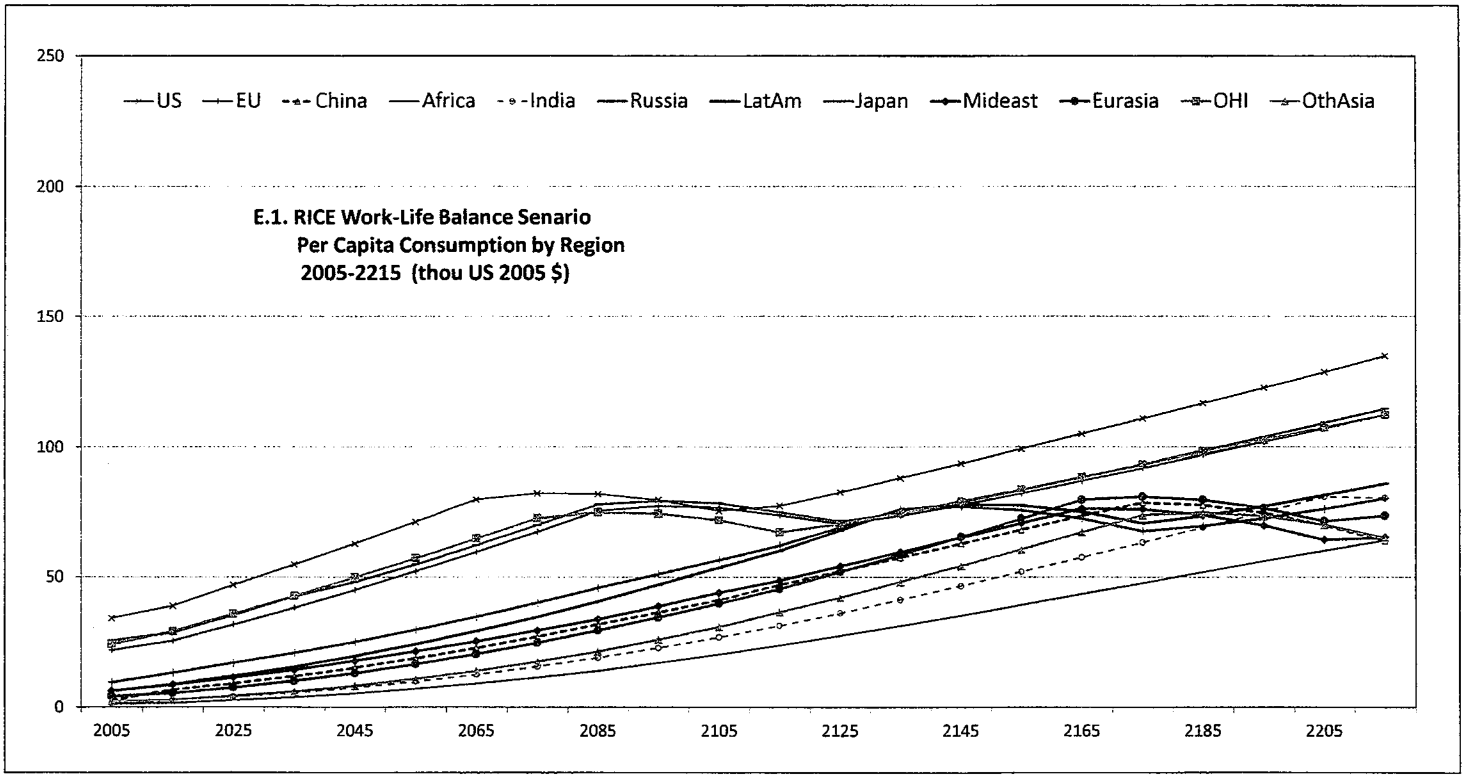
Displays D, F, and **G** show trajectories of per capita consumption under the Baseline, Flat TFP and Minus TFP scenarios, for each of the 12 geopolitical regions. Displays F and G show world per capita consumption stabilizing at an equal level in all regions, a "higher" level of about $85,000 per capita in Display F and a "lower" level of about $35,000 in Display G. In this short note we pass over the obviously central question of how such a convergence among regions is expected to happen or can be made to happen. Nor have we looked at some of the obvious macroeconomic questions that these scenarios raise. For example, to what degree can less developed regions continue to grow while more developed regions are making or have made a transition to an economic zero-growth steady-state?

Display E shows the regional trajectories of per capita consumption for the **Work-Life Balance** scenario. Households gradually reduce the amount of labor they supply to market activities. Households in each region begin reallocating labor supply when their per capita consumption reaches about $75-80,000/yr. They reduce market labor supply by roughly 10% each decade for five decades; i.e., until they are supplying about 60% of the labor supplied 50 years earlier. Total factor productivity continues to grow along the RICE Baseline trajectory, partially offsetting the curtailed labor supply during the 50-year transition. After labor supply in a region stabilizes at 60% of its pre-curtailment level, economic growth resumes at its pre-curtailment rate. Again, many key questions are left for later. For example, can total factor productivity be expected to continue to grow at its historical rates while the supply of labor is contracting by 40%? We hope to take up this and other topics shortly.

# # #


US
EU
China
Africa
India
Russia
LatAm
Japan
Mideast
Eurasia
OHI
OthAsia
D.1. RICE Baseline Scenario
Per Capita Consumption by region
2005-2215 (thou US 2005 $)
0
50
100
150
200
250
2005
2025
2045
2065
2085
2105
2125
2145
2165
2185
2205


US
EU
China
Africa
India
Russia
LatAm
Japan
Mideast
Eurasia
OHI
OthAsia
D.2. RICE Baseline Scenario
Per Capita Consumption by region
2005-2595 (thou US 2005 $)
0
100
200
300
400
500
600
700
800
900
1000
2005
2055
2105
2155
2205
2255
2305
2355
2405
2455
2505
2555


E.1. RICE Work-Life Balance Senario
Per Capita Consumption by Region
2005-2215 (thou US 2005 $)
US
EU
China
Africa
India
Russia
LatAm
Japan
Mideast
Eurasia
OHI
OthAsia
250
200
150
100
50
0
2005
2025
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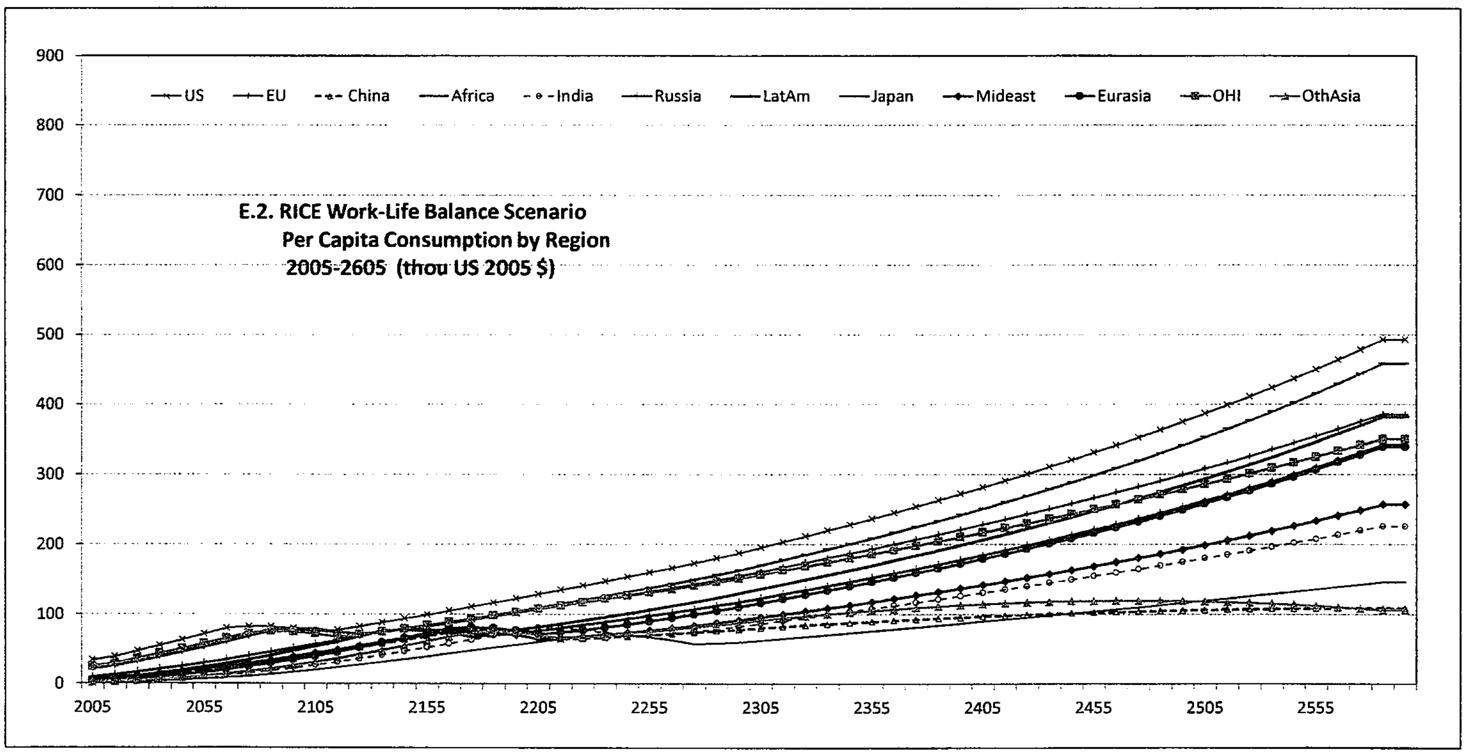
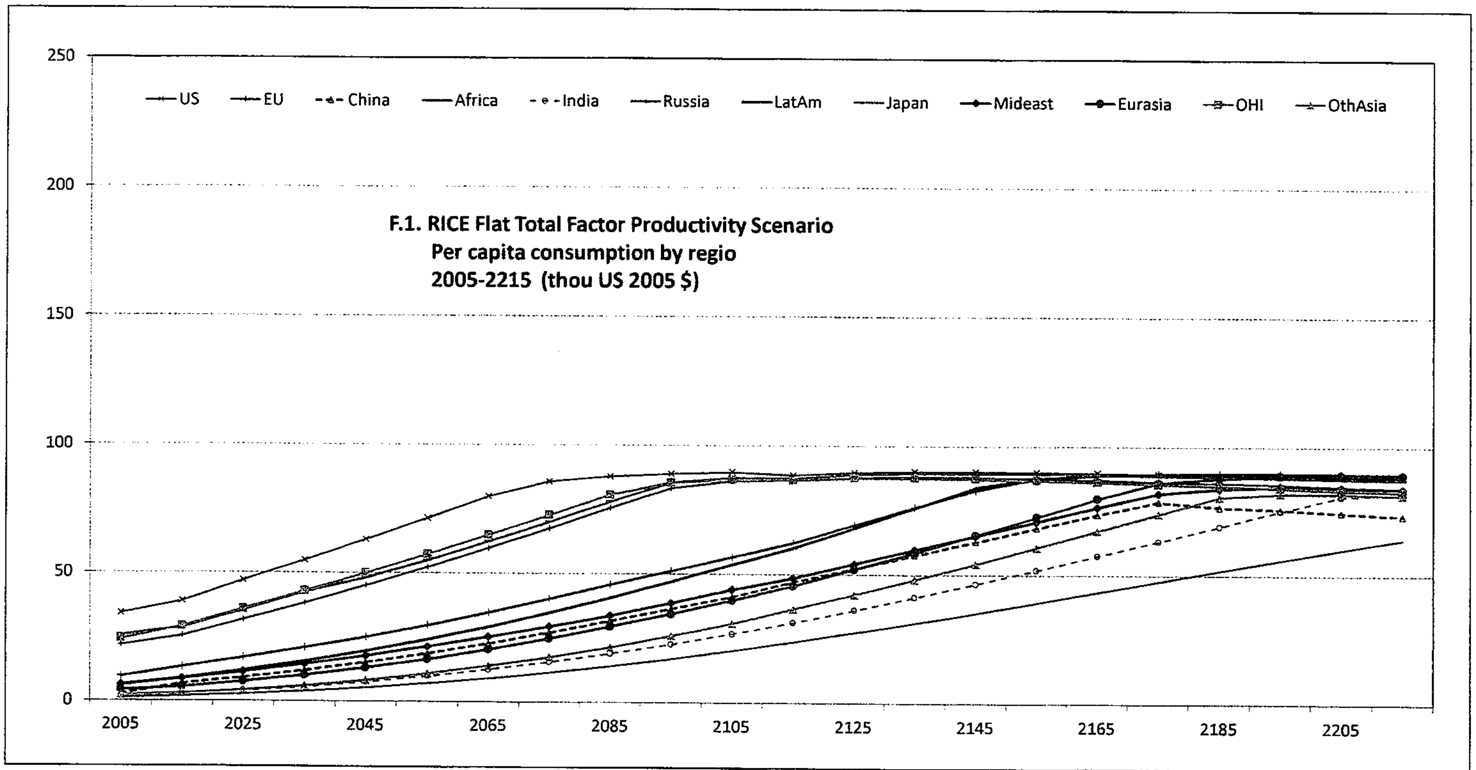
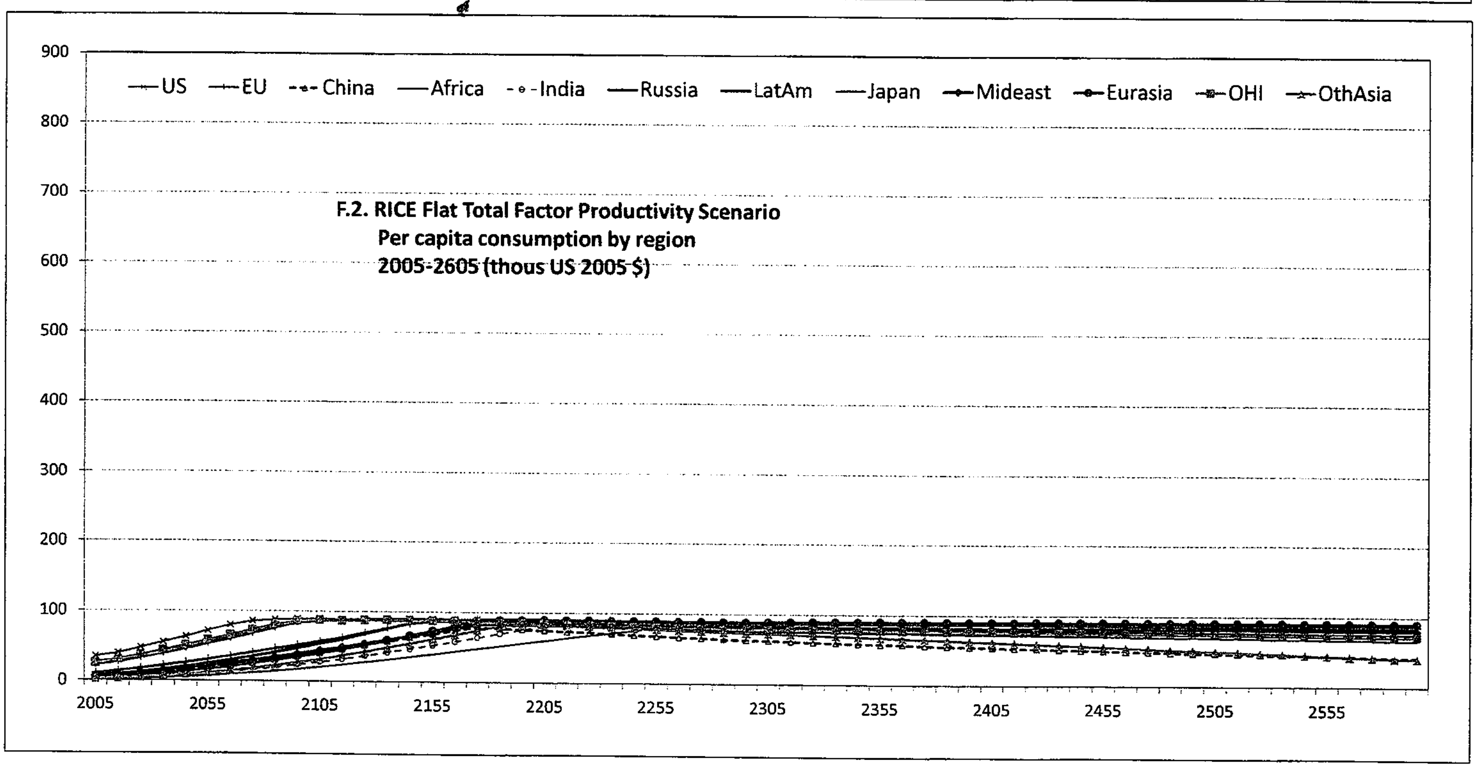
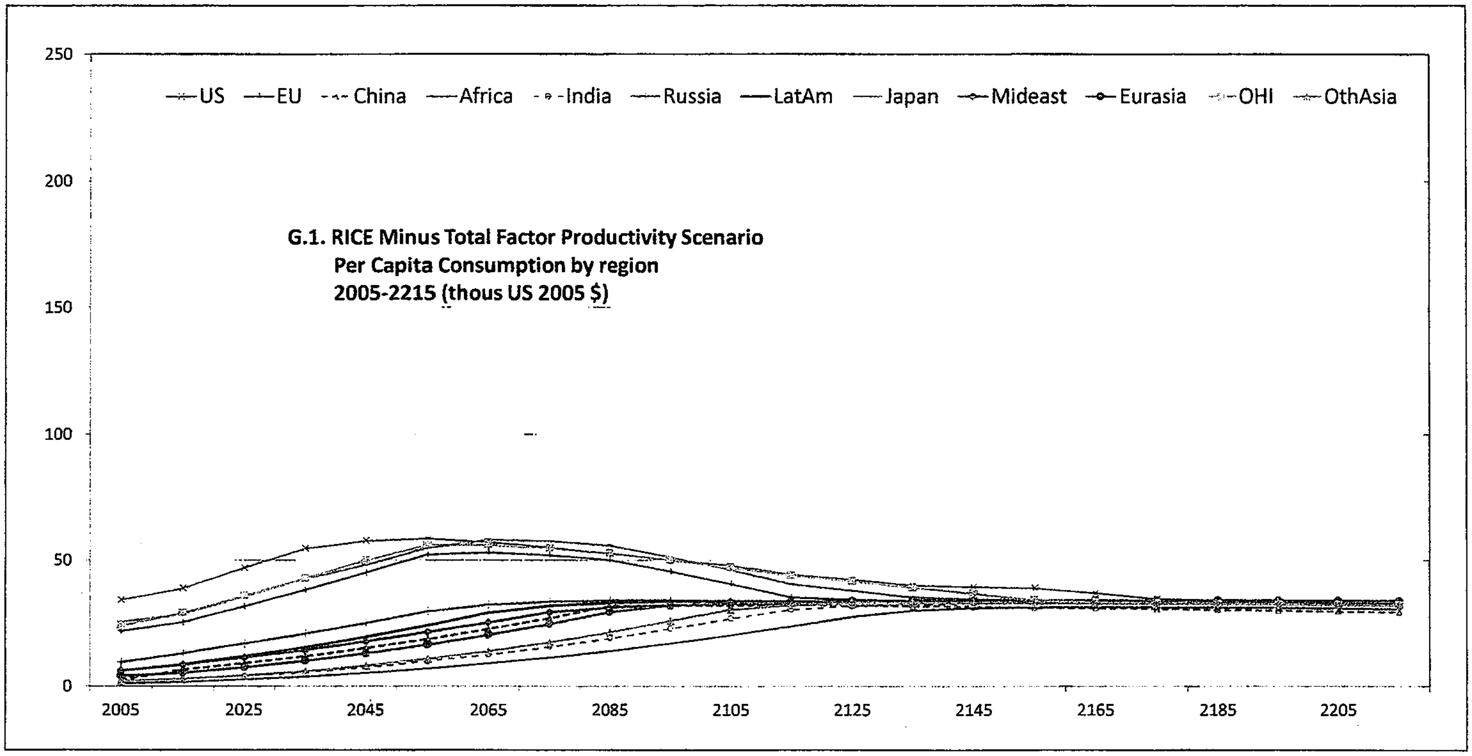
2065
2085
2105
2125
2145
2165
2185
2205


E.2. RICE Work-Life Balance Scenario
Per Capita Consumption by Region
2005-2605 (thou US 2005 $)
US
EU
China
Africa
India
Russia
LatAm
Japan
Mideast
Eurasia
OHI
OthAsia
900
800
700
600
500
400
300
200
100
0
2005
2055
2105
2155
2205
2255
2305
2355
2405
2455
2505
2555

DISPLAY F: RICE FLAT TOTAL FACTOR PRODUCTIVITY SCENARIO







G.1. RICE Minus Total Factor Productivity Scenario
Per Capita Consumption by region
2005-2215 (thous US 2005 $)
US
EU
China
Africa
India
Russia
LatAm
Japan
Mideast
Eurasia
OHI
OthAsia
250
200
150
100
50
0
2005
2025
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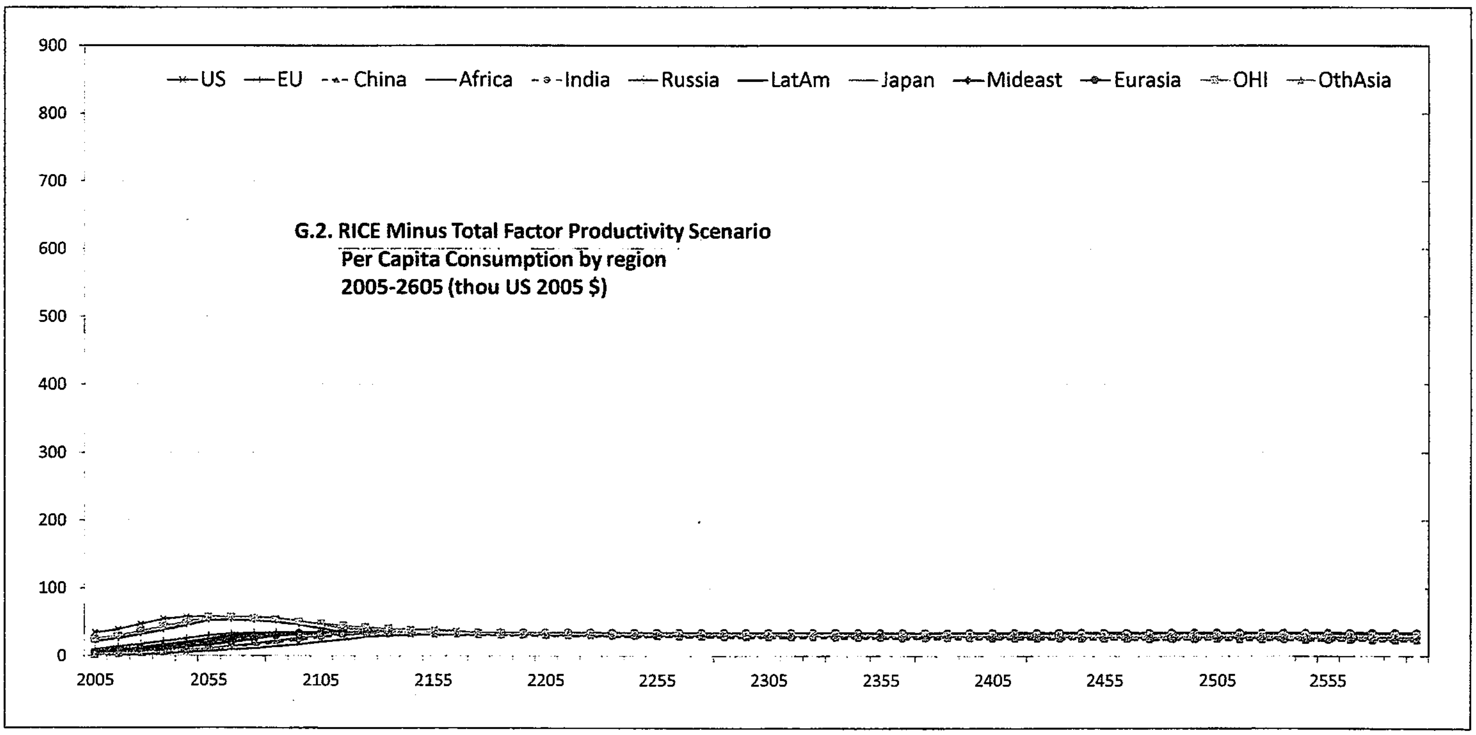
2105
2125
2145
2165
2185
2205



G.2. RICE Minus Total Factor Productivity Scenario
Per Capita Consumption by region
2005-2605 (thou US 2005 $)
US
EU
China
Africa
India
Russia
LatAm
Japan
Mideast
Eurasia
OHI
OthAsia
900
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2205
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2505
2555

ENDNOTES

[1] For this exercise we used the Excel versions of DICE-2013-R, dated 11/15/13, and RICE-2010, dated 4/25/10. These are the most recent versions of these models available and downloadable from William Nordhaus' homepage as of 6/8/16. I'd like to thank Erica Jue of Lawrence Berkeley National Laboratory for assistance in setting up and running the DICE and RICE models. Any errors in these notes are mine alone.

[2] For background on these movements see Hayes (2004, Section II.C, on Green Sustainability).

[3] DICE was initially prepared as a stripped down, globally aggregated version of RICE, and ideally the global results generated by these models should be identical. They are not, for reasons involving the Excel computational procedures, the fact that the DICE model was updated more recently than the RICE model, and for other reasons. The different results are not significant for the purposes of this brief note; in later exercises some harmonization will likely be useful.

[4] The reduction of labor supplied to market activities doesn't begin until 2025 on the assumption that it would take at least a decade of advocacy and education before enough households began changing their work-life patterns enough to be noticeable. Note that a 40% reduction in labor supplied could be achieved by 100% of the workforce cutting back by 40%, by 40% of the workforce cutting back 100%, and by many other arrangements. The RICE model makes it possible to show those in wealthier regions cutting back while those in developing regions are still working to reach per capita consumption parity. Neither DICE nor RICE contain with-region income quintiles, so it's not possible to model different patterns of labor reduction among income quintiles. Later modifications of RICE may make this possible.

[5] In the DICE model we incorporate WLB by modifying the production function equation (Equation 4, p 10, in Nordhaus and Sztorc (2013)). It is originally: **$Q(t) = [1- \Lambda(t)]\, A(t)K(t)^{\gamma}\, L(t)^{1-\gamma} / 1+\Omega(t)$,** in which:

$Q(t)$ = world GDP
$\Lambda(t)$ = climate damages
$A(t)$ = total factor productivity
$K(t)$ = Capital
γ = elasticity of output with respect to capital
$L(t)$ = Labor
Ω = costs of GHG abatement

We add the WLB variable **$\beta(t)$** to the production function as follows: **$Q(t) = [1- \Lambda(t)]\, A(t)K(t)^{\gamma}\, [L(t)(1-\beta(t))]^{1-\gamma} / 1+\Omega(t)$.** If Labor supplied to the market is reduced by, say, 5% over a given time period t, we would show $\beta(t)=.05$, and thus L(t) at .95 the value it would otherwise have been.

[6] Scenario (b), the "Moderate Carbon Tax" scenario, is my re-naming of Nordhaus' "Optimal" scenario. This scenario is the pot of gold that neo-classical benefit-cost models such as DICE and RICE are intended to generate. The trajectories of output, emissions, warming, damages, taxes, sea-level rise and everything else endogenous to the model are said to collectively maximize the sum of the net present values of all flows of benefits, including damages avoided, and costs, including both direct damages and the costs of any policy measures incurred to *avoid* damage, over the relevant time period, in this case several to many centuries. I'm of the school that believes there are too many normative and subjective judgements built into such calculations, and too much uncertainty, to warrant use of the title "optima".

[7] These first three scenarios are included in the package of DICE and RICE models that Nordhaus has made available on-line.

[8] It's important to note that the WLB proposal provides only a *temporary* reduction in the growth of economic output and thus of carbon emissions. Once the 24-hour work week or equivalent has been attained in any given region, the presumed continuing growth of total factor productivity eventually pushes GDP to the level that that region would have had had the transition to reduced labor supply never happened, and then beyond that level.

[9] The DICE and RICE models include what Nordhaus calls a *backstop technology,* defined as a non-fossil fuel technology able to substitute for any and all fossil fuels. He shows it available now but little used because it is prohibitively costly. However, it becomes increasingly cost-competitive over time, eventually undercuts even the least costly fossil fuels, and is then adopted *in toto.* Nordhaus shows this happening in DICE in 2230 and in RICE in 2255. What exactly *is* this remarkable technology? Here is the full discussion of this question in what I believe is Nordhaus' most recent treatment of the topic:

> "The backstop technology could be one that removes carbon from the atmosphere or an all-purpose environmentally benign zero-carbon energy technology. It might be solar power, or carbon-eating trees or windmills, or some as-yet undiscovered source." (Nordhaus and Sztorc 2013; p 13).

This strikes me as is a thin reed on which to stake the human future. However, it's not clear that the backstop technology plays a decisive role in any likely real-world scenario. Both DICE and RICE show moderate carbon taxes driving fossil fuel use to zero, by ~ 2100 and ~2150, respectively. The backstop comes into play only if we forego any such taxes or equivalent measures and are content to let the earth warm to over 6°C as the backstop slowly begins to substitute for fossil fuels. It's true that many analysts believe the human community will not be able to act fast enough to avoid a 2°C warming, and some argue that avoiding even a 3°-4°C warming will be a challenge. But when it becomes necessary to contemplate scenarios of 3°C and greater, there is both greater incentive to act and more time within which to act. Given all this, I'm not clear what the real-world significance of the backstop technology truly is, at least as modeled in the current DICE and RICE.

[10] For the Flat TFP scenario we modify the term for TFP growth in the original production function in the DICE model by adding the exogenous variable **$\theta(t)$**, the percent by which TFP declines in any time period, as follows: **$Q(t) = [1- \Lambda(t)]\ [A(t)(1-\theta(t))]K(t)^{\gamma}\ L(t)^{1-\gamma} / 1+\Omega(t)$**, with **$0 \le \theta(t) < 1$** at all times t.

[11] For the moment I leave the question of how this TFP slowdown is to be accomplished unanswered. It's a key question and needs to be addressed if scenarios of this sort are to have any role in the ongoing debate. Many argue that a planned slowdown and eventual end to the growth of TFP is so counter to human nature, or at least to the nature of human society and culture as these have developed since the Enlightenment, that any proposal of this sort would be so unrealistic as to be farcical. On the other hand, the prospect of positive TFP growth continuing indefinitely is itself problematic. Suffice to say that this tension is at the heart of the present inquiry.