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THE FUTURE OF GLOBAL ECONOMIC POWER

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ABSTRACT

The global economy's enormous region-specific demographic, technological, and fiscal changes raise five major questions. First, which regions will come to dominate the world economy? Second, will regional levels of per capita GDP converge? Third, will high saving rates in fast growing regions lead to a global capital glut? Fourth, does aging augur far higher tax rates in particular regions? Fifth, will automation materially influence development? This paper develops the Global Gaidar Model, a 17-region, 2-skills, 100-period, OLG model, to address these questions. The model is carefully calibrated to 2017 UN demographic and IMF fiscal data. Productivity growth and its interaction with demographic change are the main drivers of future economic power. Fiscal conditions and automation matter are secondary factors. Our baseline simulation, which sets future productivity based on each region's long-term record, predicts China and India becoming the world's top two economies with 27.0 percent and 16.2 percent of 2100 world GDP, respectively. The respective US and Western Europe shares are just 12.3 percent and 11.9 percent. Our baseline also features an evolving global savings glut, major reductions in the world interest rate, substantial aging-related increases in tax rates, and permanent differences in regional living standards. Automation makes little difference to these results. But assumed assumed productivity growth does. If recent productivity continues and demographic projections prove accurate, India will account for one third of world output in 2100 and China for over one fifth. The US output share will grow slightly while other developed countries shrink dramatically. Under more sophisticated, if seemingly less plausible projections, productivity growth in China and India dramatically slows leaving China's plus India's 2100 output share at only 16 percent, but, remarkably, Africa's at an astounding 17 percent.

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1. Introduction

This paper develops the Global Gaidar Model (GGM) to study potential changes over time in the distribution of global economic power. The GGM is a 100-period, OLG, dynamic, computable general equilibrium simulation model that combines essentially all of the world's countries into 17 regions. The GGM is carefully calibrated to UN demographic and IMF fiscal data. Our 17 regions account for 98 percent of world GDP.[7] Table 1 identifies the regions, eight of which are individual large countries – the US, China, India, Russia, Brazil, the UK, Mexico, and South Africa. The remaining regions are WEU – the European Union plus Israel, JKSH – Japan, South Korea, Singapore, and Hong Kong, CAN – Canada, Australia, and New Zealand, MENA – the Middle East, apart from Israel, plus North Africa, SAP – South Asia Pacific, SLA – South America excluding Mexico and Brazil, SOV – former Soviet Union countries in Central Asia, SSA – Sub-Saharan Africa, and EEU – Eastern Europe.

Table 1: GGM Regions and their Acronyms

Acronym	Region (Excludes Countries Modeled Independently)
US	US
WEU	Western Europe
JKSH	Japan, South Korea, and Hong Kong
CHI	China
IND	India
RUS	Russian Federation
BRA	Brazil
UK	The U.K.
CAN	Developed Commonwealth Countries (Canada, Australia and New Zealand)
MENA	Middle East and North Africa
MEX	Mexico
SAF	South Africa
SAP	South Asia Pacific
SLA	Latin America excluding Mexico and Brazil
SOV	Former Soviet Central Asia
SSA	Sub-Saharan Africa
EEU	Eastern Europe

Many factors potentially influence which regions or groups of regions will come to dominate the world economy. We focus on five – population growth, population aging, productivity catch-up (relative to the US) growth, fiscal adjustment, and automation. Our goal is to explore the potential of each factor to

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[7] Appendix table 1 lists the countries comprising our 17 regions.

influence global and region-specific growth. We treat these factors as exogenous to exhibit first-order impacts and to limit the model's complexity.

Our UN region-specific demographic data comprise country- and age-specific projections of births, deaths, net migration, and population.[8] Our baseline assumed labor-productivity (output per worker) catch-up growth-rate assumptions are based on special univariate simulations provided by the authors of Müller et al. (2019). This paper studies productivity growth in 131 countries with data ranging from 1900 to 2017. Univariate references predicting a country's future productivity growth based only on its own growth history. Our sensitivity analysis considers a) Müller et al. (2019)'s multivariate projections in which one region's labor productivity growth rate is co-determined with those of other regions with similar growth experiences and b) continuation of the region-specific productivity growth rates observed, on average, over the period 1997 to 2017.

1.1. Future Economic Power – a Preview of Findings

Table 2 shows 2017 (our base year) levels and shares of global GDP and GNI (gross national income) based on IMF PPP data. The US and China both account for roughly 16 percent of world GDP, lagging behind Western Europe (WEU plus the UK), which accounts for almost 20 percent of total 2017 output. Our baseline simulation produces a very different future world economy. At the turn of the century, China's share of world GDP is 27.0 percent, India's share is 16.2 percent, the US share is 12.3 percent, and Western Europe's share is 11.9 percent. Hence, in 2100, the 2100 combined Chinese-Indian global GDP share is 43.2 percent compared with 24.5 percent in 2017. The US and the advanced European nations, which jointly accounted for 33.5 percent of world output in 2017, account for only 24.2 percent in 2100.

These results are, however, highly sensitive to our assumed region-specific rate of productivity catch up. Relative to the recent recent record, the econometrically sophisticated study of Müller et al. (2019) predicts an almost complete end to Chinese, Indian, Russian, Eastern European, and former Soviet Union catch-up labor productivity growth. Other regions experience moderate to major improvements. Sub-Saharan Africa, for example, experiences a near doubling of its catch-up growth rate. Since the rate of catch up growth is measured relative to the US, the Müller et al. (2019)-based assumptions, combined with the UN's

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[8] See UNP (2017) We adjust, on a country-specific basis, the UN's net migration projections to ensure consistency with the UN's fertility, mortality, and population projections. The UN data are from 2017. The 2022 UN projections (https://www.un.org/development/desa/pd/content/World-Population-Prospects-2022) suggest less rapid global population growth and will be included in the next GGM update. But our findings are likely robust to the moderate changes in in the UN's demographic projections.

projected demographic changes, render the US the world's end-of-century economic kingpin, producing 18.1 percent of 2100 GDP. The next largest economy is, remarkably, Sub-Saharan Africa, with 17.5 percent of 2100 output. The China plus India output share takes a sharp drop – from 24.2 percent in 2017 to 15.8 percent in 2100.

Personally, we find the Müller et al. (2019) projections implausible given their dramatic departure from recent experience. On the other hand, nations and groups of nations have unexpectedly stopped growing, while others have unexpectedly started growing. Worker-productivity growth in Western Europe, JKSH, UK, CAN, MENA, MEX, SAF, and SLA has trailed US growth in the last two decades after exceeding and, in many cases, dramatically exceeding the US pace in the five decades following WWII. Hence, what seems implausible to us may be exactly on target. The one constant in the record of relative economic growth is its inconsistency.

Under our third assumption – that catch-up growth rates observed, on average, between 1997 and 2017 continue into the future, there is an equally dramatic sea change in relative economic clout. Now India becomes the world's leading economy, producing an astounding 33.8 percent of 2100 world GDP. China's output share rises – to 22.2 percent, which places it second to India in economic dominance. Together the two countries account for 56.0 percent of 2100 world output. The US share drops from 16.5 percent to 10.0 percent. Western Europe's (WEU and the UK) drops from 20.4 percent to 5.8 percent. And JKSH's (Japan, S. Korea, Hong Kong, and Singapore's) 2100 output share is only 1.6 percent – miles below its 7.4 percent 2017 share.

1.2. The Challenge of Assessing Demographic Change

Demographics clearly play a major role in determining future economic power. Take our results based on the recent catch-up growth rates under which China rapidly attains parity with the US in worker productivity. Our maintained assumption is that catch up with the US stops once parity is achieved. Otherwise, post-2117 relative productivity is held constant. Hence, Chinese workers are, well before century's end, as productive as US workers. But China's population is, according to the UN, almost 400 million smaller in 2100 whereas the US population is almost 120 million larger. Absent these changes, China's economy would, in eight decades, be roughly three times larger rather than roughly two times larger than the US economy.

The problem with positing demographic hypotheticals of this nature is that a country's and, thus, a region's demographics evolve as a process over many years. And dramatically altering the course of a country's demographics require immediate, massive changes in fertility, mortality, or net immigration rates – changes that may be entirely implausible. Thus, we can conceive of China's fertility rate rising rapidly from its current value of 1.7 to, say, 5.0. But the chance this will happen is essentially zero. Simulating, as we do below, more realistic demographic changes shows that they could significantly alter the future course of economic power, but gradually.

Table 2: GDP and GNI, 2017 (purchasing power parity)

Region	GDP ($)	percentage Share of World GDP	GDP Per Capita ($)	GNI ($)	Percentage Share of World GDP	GNI Per Capita ($)
US	19 543	16.4	60 110	19 967	16.8	61 413
WEU	20 312	17.1	43 312	20 304	17.1	43 295
JKSH	8 275	7.0	43 291	8 447	7.1	44 192
CHI	19 887	16.7	14 344	19 871	16.7	14 333
IND	8 277	7.0	6 183	8 187	6.9	6 116
RUS	3 807	3.2	26 347	3 705	3.1	25 643
BRA	3 019	2.5	14 525	2 962	2.5	14 253
UK	3 022	2.5	45 745	2 984	2.5	45 178
CAN	3 162	2.7	47 939	3 100	2.6	46 990
MENA	10 392	8.7	11 906	10 358	8.7	11 867
MEX	2 461	2.1	19 721	2 397	2.0	19 209
SAF	724	0.6	12 701	702	0.6	12 320
SAP	7 636	6.4	9 568	7 532	6.3	9 438
SLA	3 860	3.2	14 995	3 734	3.1	14 508
SOV	1 062	0.9	11 686	1 005	0.8	11 055
SSA	2 578	2.2	3 595	2 489	2.1	3 471
EEU	922	0.8	12 991	921	0.8	12 980
Total	118 938	100	n/a	118 668	100	n/a

Source: IMF

1.3. Relative Output and Wage Per Worker

Table 3 compares 2017 IMF data on per capita GDP and real wages relative to US values. Wages are calculated as 65 percent of GDP (labor's assumed share of GDP) per person employed. The table indicates substantial scope for catch up by China and India. China's 2017 per capita GDP and per capital average wages are just 23.9 percent and 21.5 percent of the US level. The respective 2017 values for India are 10.3 and 13.0 percent.

Another means of appreciating productivity growth is understanding what doesn't substantially impact the long-term economic order. As we show, neither major changes in global deficit policy, modeled as a global expansion of pay-go state pensions[9], nor continued automation matters much to future global GDP

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[9] As shown in Green and Kotlikoff (2006), economically identical fiscal policies can be labeled in an infinite number of ways.

Table 3: 2017 Per Capita GDP and Wages Per Worker Relative to US

Region	GDP Per Capita Relative to US Level	Wage Relative to US Level
US	100.0	100.0
WEU	72.0	81.2
JKSH	72.0	71.7
CHI	23.9	21.5
IND	10.3	13.0
RUS	43.8	44.2
BRA	24.2	25.8
UK	76.1	75.8
CAN	79.8	76.8
MENA	19.8	23.8
MEX	32.8	33.5
SAF	21.1	30.7
SAP	15.9	14.8
SLA	25.0	23.9
SSA	6.0	5.6
SOV	19.4	20.1
EEU	21.6	25.9

Source: IMF

shares.

Our study offers additional important insights. An example is the world's pending capital glut. It will arise, in significant part, thanks to high saving rates in China, India, and other regions that are aging. This simulated capital deepening dramatically reduces our baseline model's world interest rate – from 5.98 percent in 2017 to 1.18 percent in 2100. Importantly, major capital deepening arises under all three sets of catch-up growth rates.

Given our model's international capital mobility, regions like the US with low national saving rates will import capital. If capital imports are sufficiently large, such regions can maintain or even increase their shares of world GDP while seeing their shares of world GNI (gross national income) decline, potentially dramatically. The exceptionally high Chinese and Indian saving rates relative to those of advanced Western nations help explain the large projected percentage drop, discussed below, in the West's (the US and Western Europe) share of global national income compared to its drop in GDP.

1.4. Projected Population Explosions and Implosions

Table 4 and figures 1 and 2 show the United Nation's projected demographic changes as of 2017. Measured by population, the world is adding another China over the next 20 years and over two more Chinas in the course of this Century. Most of this population growth will occur in Sub Saharan Africa (SSA), India, the

Middle East, and North Africa (MENA). SSA's population, 749 million in 2017, is projected to reach 3.2 billion in 2100. That's an astronomical 4.5-fold increase and corresponds to adding 2.3 Chinas to that part of Africa. MENA's 2017 population of nearly 1 billion will almost double by 2100. India's population will rise by 175 million. And there will be 122 million more Americans in 2100 than in 2017. This is akin to adding the entire current population of the Philippines to that of the US. But this US projected 37.5 percent projected population growth is needed to maintain the US share of world population. I.e., projected global 2017-2100 population growth is also close to 40 percent.

Table 4: UN Population Projections

(millions and percentage share)

		2017			2100	
Region	Population	Share	Share 70+	Population	Share	Share 70+
US	324.5	4.4	10.3	446.5	4.2	22.2
WEU	465.4	6.4	14.0	415.5	3.9	26.0
JKSH	191.6	2.6	16.3	135.4	1.3	29.1
CHI	1,409.4	19.3	6.3	1017.0	9.6	25.6
IND	1,339.3	18.3	3.6	1514.9	14.3	19.5
RUS	144.2	2.0	9.3	123.9	1.2	19.0
BRA	209.3	2.9	5.4	189.0	1.8	27.0
UK	66.2	0.9	13.2	80.7	0.8	24.7
CAN	65.8	0.9	11.1	99.2	0.9	24.4
MENA	907.1	12.4	4.5	1,724.2	16.2	26.6
MEX	129.1	1.8	3.2	150.7	1.4	16.9
SAF	56.7	0.8	3.8	76.4	0.7	20.8
SAP	804.4	11.0	5.1	926.0	8.7	23.4
SLA	290.4	4.0	3.6	356.9	3.4	18.2
SSA	748.8	10.2	10.6	3,199.8	30.1	22.5
SOV	90.6	1.2	1.6	118.3	1.1	8.9
EEU	73.6	1.0	2.9	47.4	0.5	16.1
Total	7,316.4	100.0	6.7	1,0621.8	100.0	23.0

Other regions will experience population implosions. China's population is expected to decline by 392 million people over the Century. That decline is 20.8 percent larger than the 2017 US population. This will dramatically lower China's global population share from 19.3 percent of the 2017 total to only 9.6 percent in 2100. Asia's richest region, at least for now, – JKSH (Japan, S. Korea, Singapore, and Hong Kong) will experience a one-third decline in population. This will halve that region's 2100 global population share.

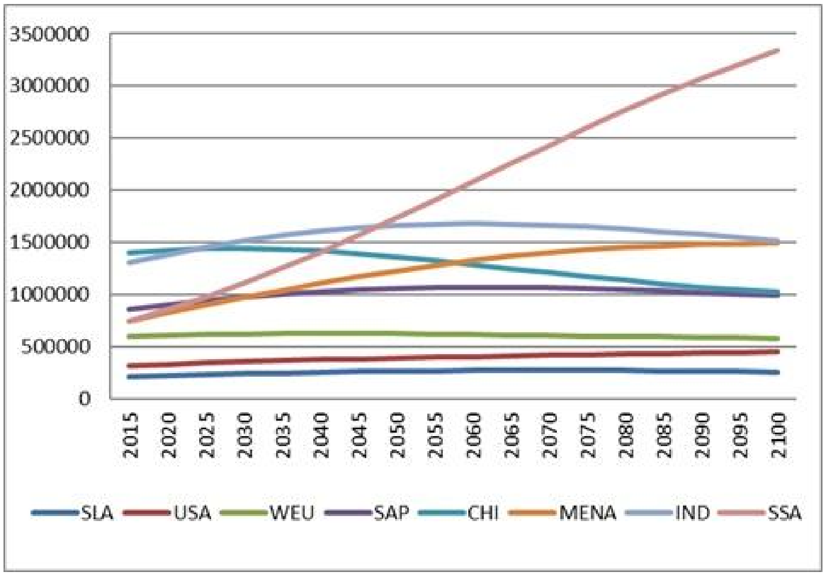

Figure 1: Population Dynamics in Regions with the Largest 2100 Populations

Source: UNP (2017), medium variant.

In 2100, the most populated regions will be SSA, with 3.20 billion people, MENA with 1.72 billion people, India, with 1.51 billion people, and China, with 1.02 billion people. Despite representing 46.3 percent of 2100 global population, SSA and MENA will account for only 11.7 percent of 2100 world output. These figures reflect our study's aforementioned bottom line – the productivity of workers is far more important than is their numbers in determining long-run economic dominance. To see this, consider the US and China, which currently account for roughly the same share of world GDP. Were today's Chinese workers as productive as American workers, China's GDP would exceed US GDP by a factor of 4.3.

1.5. Projected Global Aging

Table 4 also reports the UN's remarkable aging projections. At Century's end, those over 70 will constitute 23.0 percent of the human race. Today's figure is 6.7 percent. As the table indicates, aging is a global phenomenon with each of the world's regions projected to either get older or dramatically older. Surprisingly, aging arises even in regions, like SSA and MENA, that will experience the fastest growth in population.

Given their explicit debts and implicit pay-as-you-go pension and healthcare liabilities, aging in the US, WEU (Western Europe), JSKH, and RUSSIA (RUS) may spell significant fiscal stress. The US 70+ population share rises from 10.3

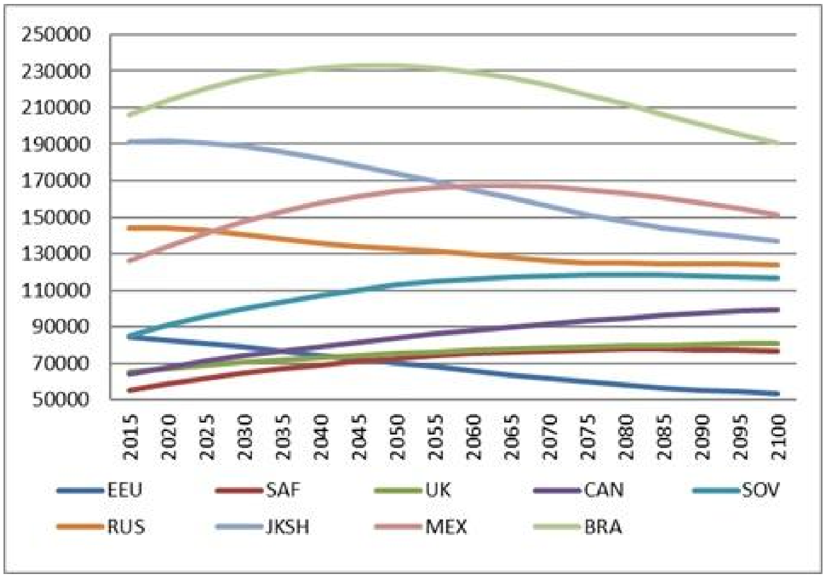

Figure 2: Population Dynamics in Regions with the Smallest 2100 Populations

Source: UNP (2017), medium variant.

percent in 2017 to 22.2 percent in 2100. In WEU, the rise is from 14.0 percent to 26.0 percent. It's 16.3 percent to 29.1 percent in JKSH. In RUS, the increase is from 9.3 percent to 19.0 percent.

China's aging scenario is particularly remarkable with its 70+ share exploding from 6.3 percent now to 25.6 percent in 2100. This reflects, of course, China's one-child policy that was only recently relaxed. But India had no such policy and it's also aging dramatically. Indian's population age 70+ now represent only 3.6 percent of its population. In 2100, they will account for 19.5 percent. Brazil's slated aging is even more impressive – from 5.4 percent to 27.0. In China's case, societal aging reflects cohorts reaching retirement having had, by edict, very few children. In India's and Brazil's cases, a projected voluntary decline in fertility is at play. Like the advanced economies, these three regions could face significant fiscal stresses if their ever expanding elderly populaces demand pension and old-age healthcare benefits or higher levels of such benefits to the extent they are now being provided. But simply covering costs of defense and other non age-specific government spending is more challenging in older economies since labor income constitutes the ubiquitous primary tax base. Regions that come under aging-related fiscal pressure will be forced to raise taxes assuming, as we do, neither a reduction in discretionary spending relative to GDP nor a decline in age-specific government spending. Higher taxes will, in turn, impact labor supply via both substitution (disincentive) effects and income effects (more work needed to maintain one's living standard). Such labor supply responses will also alter these regions' demands for capital. Thus, aging also matters to the future course of regional GDP and, thus, global economic power.

1.6. Past and Projected Catch Up

Table 5 reports 1997 and 2017 regional values of per capita GDP relative to that of the US. China's catch up is highest. In 1997, the Chinese living standard was just 3.5 percent of the US level. In 2017, the Chinese share was 13.8 percent or 3.94 times higher than 20 years earlier. India's living standard also grew compared to the US, with the 2017 ratio 2.06 times the 1997 value. Of the 17 regions, 10 closed their living standard gap with the US. Interestingly, none lost significant ground.

Table 5: GDP Per Capita as Percent of the US GDP Per Capita

	1997	2017	Catch-Up Ratio
WEU	82.9	79.8	0.96
JKSH	83.4	80.0	0.96
CHI	3.5	13.8	3.88
IND	1.8	3.7	2.08
RUS	14.3	22.0	1.54
BRA	21.5	20.6	0.96
UK	80.0	80.6	1.01
CAN	90.7	97.5	1.07
MENA	9.6	10.6	1.10
MEX	21.0	19.3	0.92
SAF	14.3	14.0	0.98
SAP	4.6	6.3	1.37
SLA	13.2	12.1	0.92
SSA	2.5	2.9	1.16
SOV	4.1	8.8	2.16
EEU	6.7	10.7	1.58

Table 6 presents the three sets of regional catch-up growth rates considered in this study. We apply these catch-up growth rates through 2117, after which we assume there is no further catch up. If a region catches up to the US prior to 2117, we assume its labor productivity stays even with the US thereafter.

The univariate (our baseline) and multivariate catch-up growth rates were, as mentioned, provided by the authors of Müller et al. (2019). The authors use a Bayesian autoregressive model estimated on macro and demographic data through

Table 6: Annual Percentage Catch-Up Growth Rates in Output Per Worker

	Univariate	Multivariate	Recent
WEU	0.76	0.02	-0.32
JKSH	1.92	-0.04	-0.22
CHI	2.54	0.17	5.60
IND	1.99	0.36	3.61
RUS	-0.06	0.06	1.53
BRA	0.27	0.25	0.36
UK	0.04	0.06	-0.46
CAN	-0.10	0.04	-0.47
MENA	0.05	0.32	-0.40
MEX	-0.64	0.24	-1.35
SAF	-0.20	0.23	-0.47
SAP	1.09	0.39	1.10
SLA	-0.67	0.38	-0.98
SSA	-0.73	0.80	0.42
SOV	0.87	0.16	3.45
EEU	0.09	0.22	2.52

Catch-up growth rates reference annual percentage change in output per worker in specified region minus the annual percentage change in US output per worker. Univariate and multivariate rates come from Müller et al. (2019)-based analysis of output per worker data. Recent rates are annual averages over the period 1997-2017.

2017 to predict country-specific per capita output levels through 2100. The table's third column provides recent catch-up growth rates from 1997 to 2017.

Clearly, the three sets of growth rates differ dramatically for particular regions. Take China, which caught up with the US at a 5.60 percent annual pace between 1997 and 2017. The univariate projected future annual catch-up rate is just 2.54 percent. And the multivariate rate is a mere 0.17 percent. In the case of JKSH, the recent rate is -0.22 percent, much lower than the 1.92 percent univariate rate and lower than the -0.04 percent multivariate rate. The univariate/multivariate differences are solely methodological.

The key difference between the multivariate and univariate projections is that the former incorporates a Bayesian method with shrinkage over parameters governing growth dynamics. This implies that the multivariate projections converge, albeit slowly, both globally and within "correlation groups" of countries as determined by Müller et al. (2019) via network analysis.[10] Therefore, growth dynamics of rapidly growing countries such as China and India will, at least in the long run, experience shrinkage toward common dynamics. The univariate forecasts are constructed by the authors using the same model and priors, but treat all data from countries apart from the one being studied as missing.[11] Our historic catch-up growth rates are based on 1997-2017 Penn World Tables (PWT 9.1) data.

1.7. Organization

Section 2 briefly reviews selected postwar economic-growth theories. Section 3 presents the model and its calibration. Section 4 lays out baseline findings. Section 6 examines the sensitivity of our findings to assumed rates of productivity catch up, demographic change, fiscal policy, and automation. Section 5 summarizes and concludes.

Our alternative catch-up productivity growth rate scenarios were just discussed. As for demographics, we first examine the impact of keeping fixed current age- and region-specific fertility rates for the next 30 years with fertility changing thereafter as determined by the current post-2017 annual region-specific projections. I.e., we delay fertility changes by three decades. Second, we run the same experiment, but with age- and region-specific mortality rates. Both of these demographic hypotheticals significantly alter region-specific population growth and

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[10] To be specific, the authors place no assumption that convergence, either to global or correlation-group specific dynamics, must occur within any given time frame. The rate is allowed to be arbitrarily slow or fast depending on past patterns. Informative priors are informed by historical data or established features and estimates of cross-country growth dynamics.

[11] Univariate and multivariate growth data are available at `http://www.princeton.edu/~mwatson/publi.html`. Note that rates as presented are relative to the U.S. growth rate, which is used to calibrate the GGM's time-augumenting technological growth factor.

aging over this Century. Neither, however, is presented as realistic possibilities. They are entertained simply to understand the potential importance of demographic change to changes in relative economic power.

We entertain two fiscal policy experiments. First, we simulate a 33 percent increase in each region's state pension funded via a payroll-tax increases. Second, we consider 50 percent increases in either the US or Chinese corporate income tax rates. These unrealistic scenarios illustrate that even major changes to baseline fiscal policy matter little to end-of-the-century GDP shares.

Automation, as proxied by major increases in capital and high-skilled worker output shares and a major decline in low-skilled workers' share, may also matter to the future distribution of economic power. AI is progressing at very different rates in different regions. In regions where it's taking hold, jobs are being erased in much the same way that motorized vehicles eliminated employment of horses. Yet,the precise nature by which AI substitutes for labor is under debate. Following Benzell et al. (2021), which employ's this paper's core model, we consider a simple formulation in which AI gradually raises capital's share in the production function in each region by 15 percentage points from 35 to 50 percent over a 33-year period, from our 2017 base year through 2050. This increase in capital's share is offset by equal percentage declines in the shares of high- and low-skilled labor.

2. Literature Review

Economists have long studied why and how countries grow. Malthus' theory of immiserating growth and Mercantilism represent early analyses. Modern growth studies begin with Rostow (1959)'s stages of growth. Rostow traced transitions from traditional societies to economies of mass consumption with both exogenous and endogenous processes at play. Gerschenkron's relative backwardness theory presented a complementary view. He emphasized the state's role in kick-starting growth and leapfrogging development stages by investing in key sectors. In contrast, Lewis (1954)'s structural change model emphasized the shift from the rural traditional sector to the urban industrial sector as vital to economic development.[12]

Successor theories include neoclassical growth theory, which stressed increases in labor and capital inputs. For example, the Harrod-Domar model, reincarnated decades later as the AK model, viewed capital investment as the main growth driver. The Solow-Swan theory (Solow (1956) and Swan (1956)) emphasized productivity growth. Uzawa (1965), Romer (1986), Lucas Jr (1988), and Rebelo (1991) made growth endogenous. Galor (2011)'s unified growth theory integrated these approaches, explaining the transition from a Malthusian growth trap to sustained growth thanks, in large part, to human capital accumulation. In contrast, Sachs et al. (1995),Sachs and Warner (1995) Easterly (2001), and Acemoglu et al. (2005) conclude that growth is largely dictated by political institutions.

Sachs (2015) offers a different view. He points to growing income inequality and social exclusion, sustained rapid population growth, geography, climate, culture, religion, natural resources, as well as environmental problems as major development constraints. [13]

2.1. Convergence

The theory of convergence dates back to contributions by Gerschenkron (1952) and Solow (1956). According to Gerschenkron (1952), diffusion of technologies was the main factor driving the convergence process. And with enough government-directed investment based on frontier levels of technology, emerging economies could bypass stages of development and quickly bring their per capita output in line with those of advanced countries. Yet convergence was not in-

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[12] See, also, Todaro and Smith (2011).

[13] Acemoglu and Robinson (2013) dispute Sach's and other traditional slow-growth explanations. They do so in part by pointing to cities that are physically adjacent and, thus, face the same development constraints and opportunities, but experience dramatically different rates of growth due to a national border endowing one city with a different rule of law, work incentives, and work ethic.

evitable. It required appropriate and sustained government intervention in the private sector as well as state-of-the-art infrastructure investments.

Neoclassical growth models, developed by Ramsey (1928), Solow (1956), and Diamond (1965), substituted capital accumulation, whether financed by domestic saving or foreign investment, as the central catch-up growth mechanism. Countries with low levels of capital per worker – a characteristic of emerging economies, will, due to diminishing returns to scarce factors, have high marginal products of capital. This makes their investments more productive leading them to experience catch-up growth.

The endogenous growth literature views growth as self propelling, with rich countries potentially growing at permanently higher rates than poor countries. Baumol (1986), using Maddison's (Rostow (1985))data for the period 1870-1979, found living-standard convergence among industrialized and middle-income countries, but divergence between the developed and undeveloped world.

Barro (1991) studies growth in 98 countries over the period 1960-1985. He finds a positive relationship between real per capita GDP growth and initial human capital and a negative relationship between real per capita GDP growth and the initial level of real per capita GDP. These findings support both endogenous and neoclassical growth models as well as conditional convergence. This alternative to absolute convergence was introduced by Mankiw et al. (1992). Their paper studies cross-country growth from the perspective of the Solow model augmented to include accumulation of human capital. The authors stress that absolute convergence requires, depending on the model in question, common technologies, rates of saving, and rates of population growth. Thus, Mankiw et al. (1992) introduced the notion of "conditional convergence," which has been widely studied[14] This literature, as well as Barro (1991) and Mankiw et al. (1992), refute absolute convergence as well as the tendency of poorer countries to catch up (see Durlauf and Johnson (1995), Sachs et al. (1995), etc.). Quah (Quah (1996a), Quah (1996b), Quah (1996c)) formulate a growth model, but include imperfect capital mobility to test the convergence hypothesis. They find scant evidence of unconditional convergence across countries. Indeed, Lee et al. (1997), who consider the growth experiences of 102 countries over the period between 1960 and 1989, show that countries are diverging instead of converging. This thesis is shared by Acemoglu (2009), who considers cross-country data for 1960-2000 and also shows a substantial increase in inequality across countries, and other studies (e.g., Durlauf and Johnson (1995) and Howitt and Mayer-Foulkes (2005)) who argue that one observes divergence, not convergence among countries starting from the mid-19th

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[14] e.g., Jones (1997), Caselli et al. (1996), Sala-i Martin (1996), King and Levine (1993), Levine and Renelt (1992), Barro (1991), and De Long and Summers (1991).

century).

Table 5's regional data certainly provides no support for absolute convergence. Between 1997 and 2017, only ten regions caught up to the US in terms of per capita GDP. China's catch up – an almost four fold increase in the standard of living ratio – was significant. India's and SOV's catch up was moderate – just over a doubling. As for the other seven, three made limited headway and four essentially no headway. Among the seven regions with catch-up ratios below 1, none lost much ground to the US. Hence, 11 of our 17 regions evinced either de minimis or no catch up with the U.S.

2.2. Prior Life-Cycle Simulation Studies

Early dynamic simulation models include Summers (1981), who assumed myopic expectations, Auerbach and Kotlikoff (1983) and Auerbach and Kotlikoff (1987), who considered rational expectations, Seidman (1984), who focused on bequest behavior, Hubbard et al. (1986), who incorporated liquidity constraints, Fullerton and Rogers (1996) and Altig et al. (2001), who included multiple goods and skill groups. These closed-economy studies primarily considered the impact of fiscal policy and tax reform.

It took many years to develop large-scale, multi-region life-cycle simulation models carefully calibrated to demographic and fiscal aggregates. Fehr et al. (2003) and Fehr et al. (2013) are early examples. And Vogel et al. (2017) is a recent example. Fehr et al. (2013) is this paper's closest cousin. It features six large regions (the US, the EU, Russia, China, Japan plus S. Korea, and India) and simulates the elimination of the US corporate income tax.[15]

3. The Global Gaidar Model[16]

3.1. Demographics and Households

As figure 3 shows, agents live to at most age 100 meaning 101 generations overlap each year. Between ages 0 and 20, agents are non-working children supported by their parents. At age 21, agents enter the workforce, earn wages, consume, and save. They also leave home. Fertility begins at age 15 and ends at 49. Children

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[15] There are five main differences between our GGM and Fehr et al. (2013). First, the GGM covers the global economy via its 17 regions. Second, the GGM contains an energy sector as in Benzell et al. (2015). Third, the GGM is calibrated based on the latest U.N. demographic and IMF fiscal data. Fourth, the GGM is designed to start from any position of the global economy, i.e., it doesn't derive its initial conditions from the calculation of an initial steady state. Fifth, the GGM permits mortality to occur at all ages, not just starting at 67.

[16] The following description of the GGM draws heavily and often verbatim from Benzell et al. (2017).

born to age-15 agents reach 21 when their parents are age 36. Those born to age-49 agents reach 21 when their parents are 70. As in Kotlikoff et al. (2007), agents between ages 15 and 49 give birth, annually, to fractions of children.[17] Fractional births facilitate calibrating realistic age-distributions of each region's population, initially and through time. Agents face an uncertain date of death, which can occur at any age. Our model has no intentional bequests. Bequests arise solely because agents are not fully annuitized, i.e., they die with assets they had hoped to spend had they lived.

Children of non-working agents under age 21 are assumed to be supported by their grandparents on a fractional basis. Each underage parent has a distribution of his or her own parents, and hence each child is fractionally assigned to a distribution of grandparents. For example, a newborn with an age-15 parent has grandparents ranging in age from 30 to 64. Grandparents treat their dependents - children and grandchildren - identically in their utility function. The maximum age of a grandparent of a newborn is 69, and hence the maximum possible age at which an agent has a dependent is 89.

The model also includes age- and region-specific net immigration. Every year new immigrants in each skill and age group arrive with the same number and age distribution of children and the same level of assets as do natives of the same skill-level and age. Each region's age- and year-specific net immigration rates are set exogenously as the residual between the projected populations based solely on the UN's fertility and mortality data and UN population projections.[18] Hence, the migration-adjusted population path tracks UN projections precisely. Once immigrants join a native cohort, they experience the same age-specific fertility and mortality rates as native-born cohort members.

Individual saving, consumption, and labor decisions in the model are governed by a time-separable, nested, CES utility function. Omitting region-specific subscripts, lifetime utility, $U_{a,t,k}$, of an agent age a at time t belonging to skill-class k takes the form:

$$U_{a,t,k} = V_{a,t,k} + H_{a,t,k}, \tag{1}$$

where $V_{a,t,k}$ records the agent's utility from their own consumption and leisure and $H_{a,t,k}$ denotes the agent's utility from their children and grandchildren's consumption. The two sub-utility functions are defined by:

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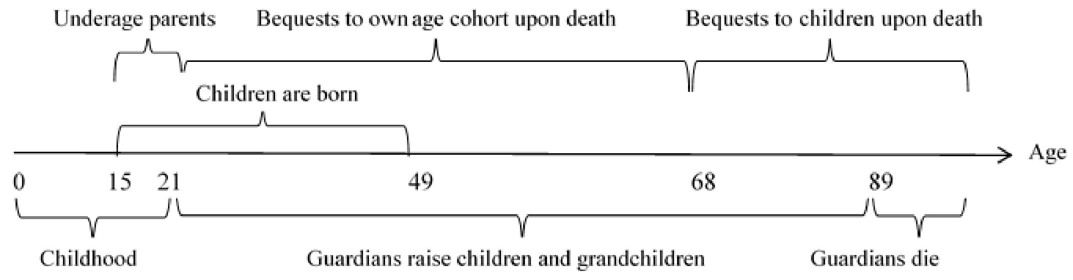
[17] We allow for underage parents to match the full distribution of the UN's fertility data. This is particularly important for modeling demographics in less developed regions.

[18] This procedure adjusts for inconsistency in the UN's projections of fertility, mortality, population, and net migration flows.

Figure 3: The individual life-cycle



$$V_{a,t,k} = \frac{1}{1-\frac{1}{\gamma}} \sum_{i=a}^{100} \left(\frac{1}{1+\delta}\right)^{i-a} P_{a,i,t} \left[c(a,i,t,k)^{1-\frac{1}{\rho}} + \varepsilon \ell(a,i,t,k)^{1-\frac{1}{\rho}}\right]^{\frac{1-\frac{1}{\gamma}}{1-\frac{1}{\rho}}} \tag{2}$$

$$H_{a,t,k} = \frac{1}{1-\frac{1}{\gamma}} \sum_{i=a}^{89} \left(\frac{1}{1+\delta}\right)^{i-a} K_{a,i,t,k} c_K(a,i,t,k)^{1-\frac{1}{\gamma}} \tag{3}$$

where $P_{a,i,t}$ is the probability that an adult agent who is age a at time t will survive to age i, $c(a,i,t,k)$ is the age-i consumption of an agent in skill class k who is age a at time t, $l(a,i,t,k)$ is the age-i leisure of an agent in skill class k who is age a at time t, $K_{a,i,t,k}$ is the number of dependents, grandchildren included for those over 30, of an agent age a at time t in skill class k when the agent is age i, and $c_K(a,i,t,k)$ is consumption per-dependent at time t of an agent age a in skill class k when the agent is age i.

The parameters $\delta, \rho, \varepsilon$ and γ denote the rate of time preference, the intratemporal elasticity of substitution between consumption and leisure, the leisure preference parameter, and the intertemporal elasticity of substitution between consumption and leisure, respectively. The probability of an agent age a at time t surviving to age i is

$$P_{a,i,t} = \prod_{z=a}^{i} [1 - d_{a,z,t}], \tag{4}$$

where $d_{a,z,t}$ is the agent's probability of dying at age z conditional on surviving to that age. Fertility, immigration, and mortality rates are based on U.N. projections through 2064, the 50th year of the model's transition. IMF fertility rates for years before 2017 are also incorporated to properly assign children to parents for the purpose of bequests. After 2064, age-specific fertility rates, immigration flows, and mortality rates are set endogenously to keep births at each age, immigration, and mortality constant at 2064 levels.

Assets $\mathrm{A}_{a,t,k}$ of a skill-k agent who is age a at time t evolve according to

$$\mathrm{A}_{a+1,t+1,k} \;=\; \big[\mathrm{A}_{a,t,k} + I_{a,t,k}\big](R_{t+1}) + w_{a,t,k}\big[h_{a,t,k} - \ell_{a,t,k}\big] - T_{a,t,k} - C_{a,t,k}, \quad (5)$$

where R_t is the pre-tax return on investment, $C_{a,t,k}$ references aggregate consumption ($c_{a,t,k} + K_{a,t,k} c_{K_{a,t,k}}$), $I_{a,t,k}$ are inheritances received in year t, $h_{a,t,k}$ is the endowment of time and $T_{a,t,k}$ is net taxes (taxes paid net of pension and other transfer payments received). $T_{a,t,k}$ includes all personal taxes, including taxes on asset income, labor income, and consumption.

3.2. Bequests and Inheritances

Agents with assets bequeath upon death. In each year, agents who are younger than age 68 bequeath to their own age cohort and skill group. Agents age 68 and above are assumed to bequeath to their adult children. Children younger than 21 cannot hold assets and are therefore do not inherit. In contrast, children born to underage parents who are adults when the parent dies do inherit. For simplicity, grandchildren don't receive bequests.

Own-cohort bequests are distributed equally among surviving members of the cohort. As death is assumed to occur at the beginning of each year, bequests are also completed prior to consumption and surviving agents consume with inherited assets taken into account. Bequests are made to children in proportion to the fraction of adult children belonging to a particular cohort and skill group at their time of death. An age-68 agent who dies, for example, bequeaths proportionately to his or her children – those aged 21 to 53. As with future factor prices, agents rationally anticipate future receipt of inheritances, incorporating them into their current consumption and labor-supply decisions.[19]

3.3. Production

Each region's GDP, Y_t, equals the sum of an energy-endowment flow X_t and aggregate non-energy output Q_t:

$$Y_t = X_t + Q_t. \quad (6)$$

Fossil-fuel production is a major public and private asset, particularly in petrol-regions like Russia and the Middle East. We model the endowment of energy in each region as generating an annual flow of the model's single consumption and

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[19] Since the GGM features only idiosyncratic uncertainty, agents exhibit perfect foresight.

investment good, net of extraction costs, with regions exhausting their energy resources at different times calibrated to extraction rates.[20]

The model specifies the size of the global energy flow, how it is distributed across regions, and the share of each region's energy endowment owned by the government. These variables are calibrated to World Bank data on the distribution of fossil fuel profits and IMF fiscal data. Each region's flow is constant until exhaustion. Since the global economy grows, the share of world GDP originating in the fossil-fuel sector declines each year until 2083 when we global exhaustion occurs.

The government's share of its region's flow of energy rents is treated as a receipt. Energy flows not owned by the government are a private asset. Total private assets are treated as the sum of government bonds, capital, and the present value of privately owned energy flows.

Non-energy output is produced via a Cobb-Douglas technology that uses capital, K_t, and two types of labor, $L_{1,t}$ and $L_{2,t}$, i.e.:

$$Q_t = \phi {K_t}^{\alpha} {L_{1,t}}^{\beta_l} {L_{2,t}}^{\beta_h}, \tag{7}$$

where α is the share of capital income in production, β_l is the share of low-skilled labor input, β_h is the share of high-skilled labor input, and $\alpha + \beta_l + \beta_h = 1$. The parameter ϕ references total factor productivity. Firms maximize profits π_t,

$$\pi_t = Q_t - \sum_{k=1}^{2} w_{k,t} L_{k,t} - (r_t + \delta_k) K_t - T_t^k, \tag{8}$$

where $w_{1,t}$ is the wage of low-skilled workers, $w_{2,t}$ is the wage of high-skilled workers, r_t is capital's rental rate, and T_t^k is corporate taxes. Note that corporate taxation in all regions is territorial.

Children inherit the skill levels of their parents. Hence, there is zero intergenerational mobility. This assumption would be of less important in the absence of bequests. But our model features bequests and assumes that in bequeathing to one's children, the high skilled bequeath to the high skilled and the low skilled bequeath to the low skilled.

Profit maximization requires

$$\begin{aligned} w_{1,t} &= \beta_l \phi K_t^{\alpha} L_{1,t}^{\beta_l - 1} L_{2,t}^{\beta_h}, & (9) \\ w_{2,t} &= \beta_h \phi K_t^{\alpha} L_{1,t}^{\beta_l} L_{2,t}^{\beta_h - 1}, and & (10) \\ r_t &= (1 - \tau_t^k) \left(\alpha \phi K_t^{\alpha - 1} L_{1,t}^{\beta_l} L_{2,t}^{\beta_h} - \delta_K \right), & (11) \end{aligned}$$

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[20] This is clearly a crude, but tractable treatment of the energy sector.

where τ_t^k references the METR.

3.4. The Government Sector

Each region's government pays for general expenditures via taxes collected from households of both skill groups and all ages, corporate tax revenues net of a rebate T_t^k, energy-sector revenue X_t^g, and new borrowing ΔB_t. General expenditures consist of purchases of goods and services, C_t^g, transfer payments that are not financed via payroll taxes, and interest on existing debt $r_t B_t$:

$$\sum_{k=1}^{2} \sum_{a=21}^{100} T_{a,t,k} N_{a,t,k} + T_t^k + X_t^g + \Delta B_t = C_t^g + \varrho B_t + r_t B_t, \tag{12}$$

where ϱ denotes the share of these transfer payments financed by general revenues. The left-hand side of 12 adds all methods of finance – the sum across cohorts and skill groups of personal taxes, total corporate taxes, energy sector revenue, and net borrowing. The terms $T_{a,t,k}$ and $N_{a,t,k}$ reference personal taxes paid by cohort age a in year t, of skill group k.

Government Revenues

To generate realistic marginal and average corporate tax rates, we assume that agents receive, via a lump-sum rebate, a fraction of gross corporate tax revenues. This rebate is denoted $T_{a,t,k}$. The size of the rebate share is calibrated by region to generate the amount of net corporate tax revenues collected in the region. For the US, the marginal effective tax rate (METR) is very high, whereas revenues are quite small. This is reconciled in the model via a rebate of 46 percent – the highest of the 17 regions.

Corporate taxes, T_t^k, equal the corporate tax rate, τ_t^k, times output net of labor costs and depreciation:

$$T_t^k = \tau_t^k [Y_t - \sum_{k=1}^{2} w_{k,t} L_{k,t} - \delta_K K_t]. \tag{13}$$

All agents are taxed on their personal income and consumption. The modeling of income taxation follows Auerbach and Kotlikoff (1987), which posits a simple quadratic function for the average income tax rate. Consumption taxation is proportional and federal and local taxes are modeled jointly.

In the baseline scenario, all governments first raise revenue with natural resource, corporate, and pension taxation. The remaining revenues needed to keep the debt-to-GDP ratio fixed come from a mix of consumption and income taxation. The income and consumption tax rates are selected to keep the ratio of revenues from these two sources fixed. These region-specific ratios are calibrated to their 2017 values.

Pension taxes on labor income are modeled independently. PY_t references the aggregate payroll-tax base. PY_t differs from total labor earnings due to region-specific ceilings on taxable wages. These ceiling are reported in table 7.

The sum of the average employer plus employee payroll tax rates $\hat{\tau}_t^p$ for the pension and non-pension transfer programs are based on each region's transfer-program-specific budget SB_t. Thus,

$$\hat{\tau}_t^p PY_t = (1 - \varrho) SB_t, \tag{14}$$

where $(1 - \varrho)$ references the share of expenditures on these programs financed by payroll taxes.

Due to contribution ceilings as well as tax evasion and avoidance, statutory payroll tax rates can differ from the average payroll tax rate. Above the contribution ceiling, marginal social security contributions are zero and average social security contributions fall with the agent's income. To accommodate this non-convexity in the budget constraint, we assume that the highest earnings class in each region with a payroll tax ceiling pays payroll taxes up to the relevant ceiling, but faces no payroll taxation at the margin. The payroll tax rate adjusts to pay a region-specific constant share of contemporaneous expenditure on pensions. The remainder is funded by general government revenues. Country-specific payroll tax ceilings, as a multiple of average wage income, are reported in table 7.

Natural resource revenues are assumed to be constant at 2017 levels.[21] They therefore decline as a share of GDP until fossil fuels deplete in 2083.

Government Expenditures

Governments have two age-specific spending programs, one general expenditure program, one non-age specific transfer program, and a pension program. The two age-dependent spending programs are education and health. The general expenditure program can be thought of as defense spending, but is calibrated on all non-education and government health programs. Non age-specific transfers are referenced as general transfers and are modeled as uniform lump-sum transfers to all adults in the region, which is calibrated to the amount of all non-pension government transfer payment.

Age-specific per-capita purchases (i.e. on health and education) adjust to changes in the size and age structure of the population while growing at the rate of non-energy sector output growth. Other government purchases of goods and services, C_t^g, such as defense spending, are fixed through time as a share of non-energy

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[21] To be clear, all data used in calibrating the model are adjusted to 2017 prices.

sector output.

Government spending on health care, education, and general transfers follows

$$E_t = \zeta Q_t \sum_{k=1}^{2} \sum_{a=21}^{100} Z_{a,t} N_{a,t,k} \tag{15}$$

where $N_{a,t,k}$ is the population at a given age, $Z_{a,t}$ is the country and spending-program specific age-expenditure profile, Q_t is non-energy sector output, and ζ is a country- and program-specific shift term, which is calibrated to correctly match program expenditure as a share of GDP. Education and health age-expenditure profiles for all countries are based on German data (see Goryunov et al. (2013). The age-general transfer profile is, as mentioned, flat.

In most regions, we assume an additional growth rate of 1.0 percent per year in health expenditures per capita from our initial year, 2017, through 2035.[22] In China and India, age-specific, per capita health care outlays are assumed to grow at a faster pace – 4 percent during the first 35 years of the transition. All government health care expenditures are classified as government consumption, whereas non-pension transfer benefits are treated as fungible transfers to households.

In the base-case transition as well as the simulation considering the elimination of all (state plus federal) US corporate income taxation, each region's government maintains its debt-to-GDP ratio at its initial level (see (12)). It does so by adjusting the proportional elements of its income and consumption taxes such that the ratio of income-tax to consumption-tax revenue remains fixed through time.

As for pension benefits, consider an agent who retires in year i at the exogenously set retirement age $\bar{a}_i$. Their pension benefit $Pen_{a,t,k}$ in year $t \geq i$ when they are age $a \geq \bar{a}_i$ is assumed to depend linearly on their average earnings during their working life $\bar{W}_{i,k}$. Thus,

$$Pen_{a,t,k} = \nu \bar{W}_{i,k}, \tag{16}$$

where ν is the pension-replacement rate. Table 7 reports pension-system parameters. Retirement age is the region's mandatory age of retirement. After this age, agents make no wage income, but receive a pension benefit. The size of the pension benefit is a linear multiple of the individuals' lifetime average wage income. After retiring, pensioners' incomes are constant at this level.

For individuals alive in 2017, we assume that wages before that year were at 2017 levels, and that their lifetime productivity follows their country's 2017 age-

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[22] As shown in Hagist et al. (2009), this is a rather conservative assumption concerning future growth in health care benefit levels.

Table 7: Pension System Parameters

	Retirement Age	Pens. Taxable Income Cap (Multiple of Avg. Wage)	Pension Replacement Rate (ν)
USA	66	None	0.552
WEU	65	2.00	0.315
JKSH	61	1.55	0.136
CHI	60	3.00	0.681
IND	60	3.00	0.387
RUS	60	None	0.561
BRA	65	None	0.891
CAN	65	None	0.217
UK	65	None	0.448
MENA	60	None	0.445
MEX	65	None	0.221
SAF	60	None	0.214
SAP	58	None	0.034
SLA	65	None	0.195
SSA	55	None	0.386
SOV	62	None	0.523
EEU	65	None	0.618

productivity profile. The share of the pension system paid for by a pension tax is equal to the ratio of pension tax revenues to expenditures in 2017. Data on retirement ages and the pension-replacement ceiling are from the World Bank and Trading Economics (2017).

With any model, such as ours, which comprises a huge number of equations (over 1 million in our case), the term black box comes to mind. This expression references two concerns. First, is the model producing correct results. Second, are its answers decipherable, i.e., do they make intuitive sense. Every economics model has equations. Their count does not determine whether the model works, i.e., accurately solves its equations. What matters is whether *all* equations are jointly solved to a very high degree of precision and whether the solution is unique. A model with 10 equations could fail one or both tests. Ours passes both tests. All of our equations jointly solve to several decimal places and there is no evidence of multiple solutions.[23] As for producing intuitive results, this is certainly the case. The above-discussed baseline and alternative simulations, predicated on different catch-up growth rate assumptions, are as expected. For example, a rapid and permanent slowdown in catch-up growth in China and India produce the expected decline in those regions' shares of global GDP. By expected, we mean on a qualitative basis. The value of the model is assessing quantitative responses. Similarly, the sensitivity results to which we now turn are qualitatively expected, but often quantitatively surprising. But in all cases, the million or so equations are joint converge in perfect coherence.

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[23] The model's iterative solution method is uniformly robust to very different sets of initial starting values.

3.5. Solution Method and Calibration

The model is solved using Auerbach and Kotlikoff (1987)'s iterative Gauss-Seidel method. The model is given 500 years to reach its new steady state. All simulations reported below converge to a very high degree of precision. Stated differently, the model's several million equations jointly hold to many decimal places. As indicted, our base year is 2017, which corresponds to the last year for which we have U.N. and IMF data.

The solution method begins with guesses of the time paths of the world interest rate, region-specific asset holdings, and region-specific supplies of skilled and unskilled workers. The amount of capital available world wide in a given period equals that period's world-wide supply of assets less total world-wide government debt.[24]

Next, demand for each non-US region's capital is calculated in each period based on (11) and that period's guessed levels of skilled and unskilled labor. Subtracting each period's total demand for capital across all non-US regions from that period's guessed global supply of capital gives us a guess of that period's US capital stock.

Based on our specified region-specific marginal effective tax rates (METR) and our region-specific guesses of capital, we can use (9), (10) and (11) to determine each region's time paths of wage rates as well as the time path of the US after-METR return to capital. Given the region-specific paths of wage rates and the world interest rates, utility maximization in each region by each generation determines new guesses of region-specific time-paths of total labor and asset supplies. The time path of the US net (post-METR) return to capital is taken as our new guess of the world interest rate time path. The new guesses of the time paths of region-specific asset holdings, region-specific labor supplies, and the world interest rate are dampened with the prior guessed time paths to form the new set of guessed paths entering into the next iteration.

As mentioned, we give the model 500 years to reach its new steady state. An extended period is needed because the global demographic structure doesn't fully stabilize until 2200. In practice, the model reaches its final steady state in about 300 years.[25] Convergence is reached after all goods, labor, and capital markets

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[24] To repeat, the ration of debt to GDP is held fixed in the baseline and policy simulations. Given each country's reported initial debt-to-GDP ratio and our calculated path of GDP, we determine each country's absolute path of debt. Since the path of world-wide capital is predicated on a guess of the path of world-wide assets, it too begins with an initial guess, which, like all guessed variables, is updated, with dampening, across iterations.

[25] Although time-augmenting technological change continues to occur after this point, our treatment of technical change ensures eventual convergence of the economy to a long-run steady state. Other formulations of technical change, e.g., labor-augmenting, rule out a steady state given the model's preferences.

clear to approximately one one-thousandth of world output.

As indicated, we calibrate the model's demographics from UNP (2017). The model's age-, year-, and country-specific fertility, mortality, and immigration rates are chosen to match official projections through 2100. After 2100, fertility rates are endogenously set each year to stabilize total births. This entails gradual changes in fertility rates that lead, by 2200, in conjunction with our assumed stable net immigration rates, to a stable population and age structure in each region. We assume that 30 percent of the US, Canadian, Western European, Eastern European, Japanese+ and Russian work forces are high skilled. For all other regions, including China and India, we assume that 25 percent of the workforce is high skilled.

We select region-specific time-preference rates, initial labor-productivity levels, and government-consumption levels to match 2017 data, the latest year for which such data are comprehensively available. In our calibration process we use each region's initial time-preference rate as the primary means to match the observed 2017 region-specific ratio of household consumption to GDP. Table 8 documents the calibration of time preferences in the model. The US is modeled as having a relatively high saving preference. This is required to prevent unrealistically high US household consumption driven by the US' disproportionately large share of world assets. This parameterization has important implications for the long-run impact of corporate tax reform. It means that the US remains a disproportionately large holder of world assets and, thus, disproportionately benefits from a global reduction in corporate income taxation.

We assume that some regions' time preference rates evolve over time. We do so for the three largest regions that discount the future less than the US. This prevents these countries from owning an unrealistically large a share of world assets in the long run. New cohorts are born with time preferences that are increasingly (according to linear interpolation) to that of the US. For example, the time preference rate of new Chinese cohorts converges to the US rate over 25 years. The preferences of cohorts in the WEU and Japan converge halfway between the original cohorts' preference and that of the US over the course of 50 years.

Each region's initial labor productivity is the main lever for determining relative GDPs by region. Each region's per-person spending on different government programs is our key means for matching observed region-specific ratios of government consumption to GDP.

Initial region-specific labor productivity coefficients (efficiency units per worker) are calibrated to match each region's initial level of per capita GDP. The age- and year-specific productivity profile of a low- or high-skilled worker age a in period t is given by

$$E(a,t) = \xi(t) e^{4.47+0.033(a-20)-0.00067(a-20)^2}(1+\lambda)^{a-21}. \tag{17}$$

This profile is taken from Auerbach and Kotlikoff (1987). The labor productivity parameter ξ is country specific. The US coefficient is fixed at 1. Those for the other regions start below 1. Productivity growth, regardless of its rate, occurs on a cohort-specific basis. Our initial conditions incorporate the assumption that all cohorts alive in 2017 in a given region have the same level of productivity. Apart from catch-up growth, all regions experience 1 percent secular growth, captured by the coefficient λ, in their time endowments. I.e., we assume that secular technological change makes agents more efficient in their use of time, whether their time is spent working or enjoying leisure.

Table 8: Time Preferences and Marginal Corporate Rate in the Model

	Time Preference δ	Corporate METR τ^c
US	-0.054	34.6
WEU	-0.053	25.4
JKSH	-0.052	35.5
CHI	-0.077	26.0
IND	-0.017	33.9
RUS	0.005	27.9
BRA	-0.034	47.3
UK	-0.044	25.0
CAN	-0.056	23.9
MENA	-0.002	17.5
MEX	0.013	19.7
SAF	0.015	14.3
SAP	0.051	25.3
SLA	0.028	27.5
SSA	0.090	30.5
SOV	-0.017	17.5
EEU	0.052	15.1

Table 9: Relative Labor Productivity, Alternative Catch-Up Growth Cases, 2017 and 2100

		Univariate			Multivariate			Recent		
	2017	2050	2075	2100	2050	2075	2100	2050	2075	2100
US	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
WEU	0.52	0.67	0.81	0.97	0.52	0.53	0.53	0.47	0.43	0.40
JKSH	0.54	1.00	1.00	1.00	0.53	0.53	0.52	0.50	0.48	0.45
CHI	0.13	0.30	0.56	1.00	0.14	0.14	0.15	0.78	1.00	1.00
IND	0.07	0.13	0.22	0.36	0.08	0.09	0.09	0.23	0.55	1.00
RUS	0.25	0.25	0.24	0.24	0.25	0.26	0.26	0.41	0.60	0.88
BRA	0.16	0.17	0.19	0.20	0.17	0.18	0.20	0.18	0.20	0.22
UK	0.67	0.68	0.69	0.69	0.68	0.69	0.70	0.58	0.51	0.46
CAN	0.64	0.62	0.60	0.59	0.65	0.66	0.66	0.55	0.49	0.43
MENA	0.11	0.11	0.11	0.11	0.12	0.13	0.14	0.10	0.09	0.08
MEX	0.22	0.18	0.15	0.13	0.24	0.25	0.27	0.14	0.10	0.07
SAF	0.13	0.12	0.12	0.11	0.14	0.15	0.16	0.15	0.17	0.19
SAP	0.11	0.16	0.21	0.27	0.13	0.14	0.15	0.16	0.21	0.27
SLA	0.15	0.12	0.10	0.09	0.17	0.19	0.21	0.11	0.08	0.07
SSA	0.05	0.04	0.03	0.03	0.07	0.08	0.10	0.06	0.06	0.07
SOV	0.12	0.16	0.20	0.25	0.13	0.13	0.14	0.37	0.86	1.00
EEU	0.11	0.11	0.12	0.12	0.12	0.12	0.13	0.25	0.47	0.87

We set each region's initial debt-to-GDP ratio to ensure that the model's interest payments are the same share of GDP as observed in the 2017 data.[26] Other fiscal parameters determining per capita government spending on health care, education, and general outlays are set to match observed expenditures as a share of GDP.

Our simulations keep debt fixed as a share of GDP in each region. Other tax rates are also endogenous. For example, a region-specific fixed percentage of government pension outlays is covered by a dedicated payroll tax that adjusts through time with changes in pension outlays. Region-specific corporate METRs are set per the values reported in table 8 and then a rebate is calculated to match corporate tax revenues as a share of GDP. Revenues in some regions are supplemented by natural-resource licensing, which we calibrate from the government's share of total fossil-fuel rents. The remaining revenues needed to keep debt-to-GDP fixed come from a mix of consumption (i.e., VAT, sales, and excise) taxation and income taxation. We chose parameters for the share of revenues raised by these two taxes to match the data. We also calibrated the progressivity of the income tax. Effective marginal consumption, income, and payroll tax rates in each region and for each skill group are calculated annually to maintain initially observed

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[26] The debt-to-GDP ratio is set at a negative value for regions with positive net government assets.

revenue-shares and degrees of progressivity.

Each region's income tax is modeled via

$$R_t = \tau_t B_t + \frac{\varphi_t B_t^2}{2}, \tag{18}$$

where R_t is total income-tax revenues, τ_t is the endogenously calculated average income tax rate, B_t is total labor income, and φ_t an exogenously set progressivity term. For the US, the WEU, JKSH, CAN, EEU, SAP, MENA, SLA, and SSA, we set φ_t to 0.3. For the other regions, we set the value to zero.

Relative asset holdings in each country are matched to data on privately held assets from Global Wealth Report Credit Swiss (2017). Initial age-asset distributions in each country are set to match the asset age-distribution reported in the US Survey of Consumer Finances (SCF) (Bricker et al. (2014)), with assets defined as the sum of households' regular financial assets, retirement accounts, plus home and real estate equity net of debt. [27] The overall level of global private assets is set to generate an initial interest rate of 5.98 percent in 2017.

Region-specific values of fossil-fuel rents are matched, with appropriate GDP weighting to regional values, to World Bank data on fossil-fuel rents as a share of GDP. The government's share of this flow is matched to the natural-resource revenue share of government income taken from the IMF Commodity Exporters data set[28]. For some countries the data for government revenues is absent.[29] Fossil fuel extraction and reserves data for oil, gas, and coal come from the US Energy Information Administration. Based on these data and assuming time-invariant extraction, we calculate the duration of fossil fuel extraction for each region.

Data on 2017 GDP (measured at PPP) and household consumption as a share of GDP data are based on the IMF World Economics Outlook database. The data for calibrating government outlays and receipts GDP come from the IMF Government Finance Statistics (GFS) database. All data are for general government (central, state, and local governments as well as social security trust

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[27] We take weighted averages of assets for each age cohort in the 2016 SCF from age 22 to 95 and perform spline smoothing with a smoothing parameter of 0.68 to derive a smooth age-asset path. Because labor force participation begins at 21, we set the asset holdings of 21 year-olds to zero. The initial age-asset profile of high skilled workers is assumed to have the same shape as that of low skilled workers, with the levels differing by the year-0 high skill wage premium. Both profiles are adjusted such that the weighted sum of assets of all age and skill groups in each region equals the region's asset holdings.

[28] Global Wealth Report Credit Swiss (2017)

[29] If the value of rent is 1 percent of GDP or less, we assume that government revenue is zero. For other regions, e.g., India and Mexico, with a higher value of rent, we assume that 100 percent of rent goes to the government. For several other countries we impute missing data based on data for other countries in the region.

funds) combined. For countries with missing data, we impute values from countries with similar characteristics. As for government expenditures, the program calculates interest outlays based on the region's prevailing debt holdings and the model's computed world interest rate. General government consumption (discretionary spending) as a share of GDP is held fixed at each region's observed 2017 share. Age-related expenditures on healthcare, education, social protection, and state pensions are assumed to grow based on observed or imputed age-healthcare, age-education, age-social protection, and age-pension profiles as well as labor productivity. All other government expenditures are treated as per capita transfers that grow with labor productivity and population.

On the revenue side, we treat revenues from taxes on goods and services and customs and other duties as consumption taxes. Income taxes are treated as taxes on wages and household asset income. Corporate taxes are treated as taxes levied on firms' rentals of capital. Payroll tax rates to fund state pensions and other targeted outlays are calibrated based on the IMF GFS-data on social insurance contributions. Consumption tax rates are calibrated based on IMF GFS tax revenue database. All remaining government revenue, apart from corporate income tax revenue, reflects taxable personal income, the value of which is used to determine the proportional component of the income tax.

3.6. Matching the Data

As Appendix table 4 shows, our model's region-specific 2100 total population counts match the U.N.'s projections very well in general and extremely well in particular cases. For example, the model predicts the US population at 443.6 million at the end of the century, which is within 1 percent of the U.N. projection of 446.5 million. Another example is China. The model predicts China's 2100 population at 986.2 million. This is 3 percent of the U.N.'s 1017.0 million estimate.

Appendix table 2 compares projected and modeled population age structures for 2017 and 2100. Because the 2017 U.N. population counts by age are part of the model's initial conditions, the model's 2017 age structure conforms exactly to the data. What's remarkable is how well, generally speaking, the model tracks regional age structures through time. For the U.S, the UN predicts 10.8 percent of the population will be between the ages of 20 and 29 in 2100, with 21.5 percent between the ages of 70 and 100. The model's shares are 10.8 percent and 21.5 percent, respectively. Another example is SLA, which references Latin and Central America apart from Mexico and Brazil. In 2100, the U.N. SLA population shares at ages 20-29 and 70-100 are 17.0 percent and 23.7, respectively. The corresponding model's shares are 17.1 percent and 22.7 percent.

Appendix table 5 considers the match between the IMF and the GGM measures of 2017 macro indicators. As is immediately clear, the GGM does an excellent job matching region-specific relative GDPs, ratios of private and government consumption to GDP, shares of world assets,[30] and fossil-fuel rents as shares of GDP. Appendix table 6 shows the precision of our government fiscal policy calibration. Aggregate macroeconomic variables, such as relative GDPs, fossil fuel profits as a percent of GDP, and shares of world assets are also calibrated.

Our calibration strategy entails targeting IMF-observed region-specific expenditure shares and letting the GGM's tax rates adjust accordingly.[31] Appendix table 6 shows a tight fit of the model to these government spending shares. The endogenous revenue shares line up less well. This reflects two things. First, some regions ran larger deficits in 2017 than maintenance of a fixed debt-to-GDP ratio would entail. The US is a good example. The IMF's accounting suggests the US government (federal, state, and local) deficit was 5.7 percent of GDP in 2017, which is far higher than the 2.6 percent real GDP growth recorded in that year. As indicated, our baseline as well as policy simulations assume a fixed ratio of debt to GDP. Second, the GGM includes no aggregate risk. Hence, the model has no equity premium; i.e., the government borrowing rate equals the world interest rate. Since we calibrate each region's initial debt level to match observed government net interest payments as a share of GDP, our initial government debt levels are lower than the official figures. Stated differently, since the interest rate in our model exceeds, for most regions, the actual rate paid by governments, we reduce the initial debt to match government interest payments as a share of GDP.

4. Findings

4.1. The Evolution of Economic Power Under Baseline Assumptions

Table 10 shows the remarkable end-of-century transformation in world economic power predicted by our base-case (univariate) model. It also shows the extreme sensitivity of this prediction to assumed productivity catch-up growth rates. As of 2017, the advanced economies – USA, WEU, the UK, and JKSH – accounted for 43.0 percent of global GDP. The corresponding share of China plus India is. In 2100, the output share of today's advanced economies will equal 29.3 percent, whereas China plus India's share will equal 43.2. Sub-Saharan Africa (SSA) and Post-Soviet Middle Asia (SOV) also gain a slightly larger share of world economic power. Take SSA. Although its share of world GDP rises by 76 percent, its absolute share remains trivially small – just 3.7 percent. This is remarkable given that its share of global population rises, as shown in table 4, from 10.2 percent in 2017 to

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[30] The SAF and SOV asset shares in the GGM are positive, but less than 0.1 percent.

[31] Pension revenues as a share of GDP appear to be particularly low on both the IMF and GGM measures. The reason is that these revenues reference only taxes collected to cover retirement benefits; i.e., the IMF allocates other pension-system outlays, such on disability benefits, to ”Transfers and Benefits Different from Pensions.

30.1 percent in 2100. Regions such as Russia and Middle East and North Africa loose relative economic power due to both to slow catch-up productivity growth as well as the eventual loss of fossil fuel revenue. For example, Russia's global GDP share drops from 3.3 percent to 1.1 percent. The UK is another region with a notable decline in global economic power - from 2.6 of world GDP in 2017 to 1.6 percent in 2100.

Our baseline simulation also suggests that change in NI (national income) shares can differ substantially than from changes in GDP shares. This holds for the US, whose global GDP share falls through 2100 by 25.0 percent whereas its global NI share falls by 35.9 percent. Since national income tells us what a country earns, not what it produces, including with capitxal owned by foreigners, it is, arguably the more appropriate measure of economic power. The US figures are easily understood. Currently, Americans have substantial assets, but a relatively low saving rate. Consequently, its NI share exceeds its GDP share. But, over time, the low US saving rate as well as the abundance of net capital imports spells a larger percentage decline in NI than GDP.

4.2. Catch Up Based On Multivariate Analysis

Simulating the GGM with Müller et al. (2019)'s multivariate productivity growth rates generates remarkably different results. Rather than becoming the economic kings of the block, China and India's joint global GDP share drops from 24.0 percent in 2017 to 15.8 percent in 2100. The current developed world – the US, WEU, UK, and JKSH – also experiences a decline in GDP share – from 43.3 percent to 34.4 percent. Yes, the US share rises from 16.1 percent to 18.1 percent. And, yes, the UK share rises, if slightly. But the WEU's share falls from 17.3 percent to 10.8 percent. And JKSH's share drops from 7.3 percent to 3.1 percent. If China and India as well as the current developed world lose market share, who gains? The answer, as table 10 shows, is SSA. Sub Saharan Africa's GDP share rises from just 2.1 percent in 2017 to 17.5 percent at the century's end. Frankly, we're skeptical of these multivariate results. The notion, conveyed in table 6, that rapid catch-up growth in China, India, WEU, and JKSH will end, indeed, quickly end, and that SSA's catch-up growth will double seems too detached from recent recent experience to be plausible. Yet, Müller et al. (2019) is a serious study using state-of-the-art econometric techniques and all available data. Hence, the multivariate results can't simply be dismissed. They remind us that our paper's goal is not to prove what will happen, but to suggest the range of outcomes that may happen. We leave it to the reader to apply their own priors to the different sets of catch-up growth assumptions.

4.3. Catch Up Based On Recent Experience

Table 10's recent growth rate results are equally stunning. Recall, the recent growth rates are simply the averages calculated based on catch up during the

20 years prior to 2017. India now becomes the planet's super superpower with its 2100 share of the global economy rising from 6.8 percent to 33.8 percent. As for China, its GDP share rises from 15.7 percent to 22.2 percent. Thus, under this scenario, China and Indian combine, in 2100, to produce 56.0 percent, i.e, more than half of world output! The two regions end up with a slightly larger – 56.7 percent – of world national income.

Why is India's 2100 economy 50 percent larger than China's under this productivity growth rate assumption? The reason, as indicated in Appendix table 2, is demographics. India's 2100 population is almost 50 percent larger than China's. And, by 2100, Indian and Chinese labor productivity are equal. Hence, China's productivity edge vis a vie India dissipates through time.

All other economies see their economic influence shrink or remain roughly fixed compared to the base case. For the U.S. the picture is particularly grim. It's share of the world economy falls to just 10.0 percent by Century's end. The story for Western Europe, including the UK, is even more shocking. In 2017, WEU and UK account for 25.2 percent of world output. But if recent catch-up rates prevail, their 2100 share will be just 6.4 percent! I.e., Western Europe will evolve from being the world's largest economy to being one of its smallest. The Middle East despite its projected massive population growth will see a halving of its economic influence. As for SSA, its population will increase by 2.451 billion people but its share of world GDP will rise by only 1.6 percentage points. Assumed catch-up growth rates also matter dramatically to overall global growth. World GDP and national income increase by 2100 by a factor of 8.7 under univariate rates, 5.1 under multivariate growth rates, and 11.2 under recent growth rates.

4.4. Aging and Tax Rates

Table 11 shows, for the univariate case, huge increases in average tax rates across all regions between 2017 and 2100. This reflects, as discussed above, the remarkable aging projected for all regions through century's end. Take China. It's payroll tax rises from 8.1 percent to a 36.5 percent. And its consumption tax increases from 36.5 percent to 53.5 percent. These increases are far more dramatic than in, for example, JKSH. It's combined payroll, consumption, and income tax rates increase by 11.4 percentage points compared to a 34.4 percentage-point increase in China. This reflects the far more significant process of aging underway in China. For example, the 2017 population share of those 60 and over is 16.2 (See Appendix table 4.). In 2100, the projected share is 37.5 percent. For JKSH, the 2017 share is 29.1 percent. In 2100, it's 40.5. Hence, the elderly share rises by 21.3 percentage points through 2100 for China. For JKSH, there's an 11.4 percentage-point increase.

In 2100, China ends up with substantially higher payroll and consumption tax rates than does JKSH. This is true even though JKSH's share of those 60

Table 10: Regional Shares of Global GDP and NI, 2017 and 2100, Baseline

(percent)

	Univariate GDP		**Multivariate GDP**		**Recent GDP**		**Univariate NI**		**Multivariate NI**		**Recent NI**	
	2017	2100	2017	2100	2017	2100	2017	2100	2017	2100	2017	2100
USA	16.4	12.3	16.1	18.1	16.5	10.0	19.2	12.3	19.0	19.1	19.2	9.9
WEU	17.1	11.9	17.3	10.8	17.8	4.8	18.3	12.1	18.5	11.9	18.8	4.9
JKSH	6.9	3.5	7.3	3.1	7.4	1.6	7.9	3.8	8.2	3.7	8.3	1.7
CHI	16.6	27.0	16.9	7.8	15.7	22.2	16.0	27.8	16.2	8.8	15.2	23.1
IND	6.9	16.2	7.1	8.0	6.8	33.8	6.0	15.9	6.1	8.5	5.8	33.6
RUS	3.3	1.1	3.1	1.9	3.1	2.2	2.7	1.0	2.7	1.7	2.7	2.1
BRA	2.5	1.3	2.4	2.1	2.6	0.4	2.1	1.2	2.1	1.9	2.3	0.4
UK	2.6	1.6	2.6	2.4	2.6	1.0	3.1	1.7	3.0	2.6	3.1	1.0
CAN	2.6	1.9	2.6	3.0	2.6	1.2	3.3	2.0	3.2	3.4	3.3	1.3
MENA	8.7	8.3	8.5	9.9	8.6	8.4	7.1	8.0	7.0	9.5	7.1	8.2
MEX	2.1	0.8	1.9	2.1	2.1	0.4	1.9	0.8	1.7	1.9	1.9	0.4
SAF	0.7	0.4	0.6	0.8	0.7	0.3	0.6	0.4	0.6	0.7	0.6	0.2
SAP	6.6	7.4	6.6	7.0	6.6	6.0	5.8	7.2	5.9	7.0	5.8	5.9
SLA	3.3	1.3	3.1	4.2	3.3	0.9	2.9	1.3	2.7	3.8	2.9	0.8
SSA	2.1	3.7	2.1	17.5	2.1	3.7	1.9	3.3	1.7	14.3	1.9	3.5
SOV	0.8	0.9	1.0	0.9	0.8	2.4	0.8	0.9	0.8	0.9	0.8	2.4
EEU	0.8	0.2	0.8	0.4	0.7	0.8	0.6	0.2	0.6	0.3	0.6	0.7

Table 11: Tax Rates, 2100, Baseline, Univariate Case

(percent)

	Payroll Tax		Consumption Tax		Income Tax		Corporate Tax	
	2017	2100	2017	2100	2017	2100	2017	2100
USA	10.4	16.1	8.8	9.9	21.2	26.3	34.6	34.6
WEU	21.3	17.2	24.8	34.8	16.6	21.5	25.4	25.4
JKSH	16.9	18.3	15.3	20.3	9.9	14.9	35.5	35.5
CHI	8.1	23.4	36.5	53.5	5.2	7.3	26.0	26.0
IND	3.0	5.5	13.2	20.2	5.1	6.4	34.0	34.0
RUS	12.1	16.2	22.9	46.3	9.4	16.5	27.9	27.9
CAN	3.7	4.2	13.9	18.1	20.3	29.4	23.9	23.9
EEU	12.6	23.1	29.8	45.6	10.5	13.2	15.1	15.1
SAP	0.5	1.0	15.1	22.1	2.9	3.7	25.3	25.3
BRA	16.9	30.8	27.0	39.0	10.8	13.3	47.3	47.3
MEX	3.5	8.8	12.6	17.5	9.0	11.5	19.7	19.7
SAF	0.9	2.8	25.0	36.2	21.7	26.8	14.3	14.3
MENA	7.9	13.8	23.1	40.9	5.6	8.2	17.5	17.5
SLA	4.9	9.5	21.7	27.2	10.4	11.3	27.5	27.5
SSA	3.6	14.7	17.5	17.9	9.5	9.5	30.5	30.5
SOV	3.1	7.0	15.0	33.1	5.4	10.1	17.5	17.5
UK	12.2	13.9	19.1	23.8	14.5	19.0	25.0	25.0

plus in 2100 than is China. On the other hand, the Chinese income tax ends up considerably lower. This reflects differences in replacement rates across the regions, different reliance on particular types of taxes, and different relative sizes of the different tax bases.

The results in table 11 suggest several key points. First, unlike the presumption of many adherents to supply-side economics, countries can grow even in the face of very high rates of taxation. The reason is that, based on our empirically-grounded calibration, income effects from higher tax rates exceed substitution effects. Hence, as tax rates rise, workers choose to work more hours to maintain their living standards rather than substitute into leisure. Second, future tax rates at the levels simulated may be hard to collect. Third, we have abstracted from fiscal progressivity. If marginal tax rates rise relative to average taxes in the course of average tax rates being increased, there will be more substitution toward leisure. Finally, high-skilled workers, who will likely be the worst hit by tax hikes, may choose to leave the country.

5. Sensitivity Analysis

This section runs six sensitivity analyses – automation that continues through 2050, modeled as a rise in capital's share in the production function in each region from 35 to 50 percent, holding all age- and region-specific fertility rates fixed for 30 years, holding all age- and region-specific mortality rates fixed for 30 years, raising state pensions by one third in all regions on an immediate and permanent basis, and increasing, by not in concert, the US and Chinese carbon tax rates by 50 percent.

Table 12 considers various shock and policy scenarios. Automation, modeled as a rise in capital's share of output, promotes global growth, albeit less than one might expect. In 2100, the world's output is 9.8 percent higher. The beneficiaries of automation are principally countries with higher-skilled labor, including the US, Western Europe, Japan, Korea, Singapore and Hong Kong, the UK, Canada, Australia and New Zealand. Under multivariate growth rates, world GDP drops since those countries who would otherwise benefit the most from automation are projected to grow slower. Thus, gains for the US, Western Europe, Japan, Korea, Singapore and Hong Kong, the UK, Canada, Australia and New Zealand are smaller, so are losses for China, Middle East and North Africa, Sub-Saharan Africa and South America. Raising capital's share assuming recent productivity catch up also entails a very small impact on the world's distribution of output as the change in technology is overpowered by higher cross-regional growth rate discrepancies.

Keeping cohort-specific fertility rates fixed for the next 30 years is our next counterfactual. It raises the value of 2100 global GDP in the univariate simulation by 11.6 percent. The winning regions, in terms of 2100 GDP shares, are those with otherwise significantly declining projected fertility: The list is Sub-Saharan Africa, Middle East and North Africa, South Africa, India, Post-Soviet Asia, South America, South Asia and Pacific and Mexico. Consider, for example, MENA (the Middle East and North Africa), whose fertility rate is projected to fall over the century from 3.04 to 1.59. It's univariate, multivariate, and recent baseline 2100 GDP shares are 8.3 percent, 9.9 percent, and 8.4 percent. Holding fertility fixed for three decades increases these long-term shares to 12.5 percent, 12.9 percent, and 11.8 percent, respectively.

US fertility is scheduled to remain constant at its 2017 value of 1.86. Nonetheless, America's long-term economic position would is significantly in this fertility rate counterfactural. The 2100 US univariate, multivariate, and recent GDP shares fall from 12.3 percent, 18.1 percent, and 10.0 percent, respectively to 10.2 percent, 12.3 percent, and 7.6 percent, respectively. This decline in US economic power reflects, of course, the fact that other regions are economically larger under the experiment.

Clearly, since the US fertility rate is stable over time, keeping it on its baseline path for 30 years while holding all other region's fertility rates constant during this period would produce no impact of any kind regardless of catch-up growth assumptions. This example demonstrates the rather obvious point that external fertility can be far more important than internal fertility in impacting a country's relative economic might. Another example is SSA, whose fertility rate is forecast to drop over the century from 5.09 to 1.52. This is the most dramatic change in fertility in any of the GGM's 17 regions. We know from table 12 that keeping SSA's and all other regions' fertility rates fixed for 30 years produces huge increases in SSA's end-of-century share of global output. But were fertility to remain fixed for this period only in SSA, its 2100 share of output would be somewhat lower in all catch-up cases. The reason is that the counterfactual, if applied globally, reduces world output, on balance. Hence, if applied to SSA, its higher output would be a smaller share of a larger 2100 world GDP.

Our bottom line regarding global fertility changes? If they are sizable and last for many decades, they can materially alter future economic power. Yet, the impacts are small compared to those associated with different sets of productivity catch up.

Fixed mortality has a substantial negative impact on the global economy measured as a -14.9 percent loss of world GDP in the case of univariate catch-up growth rates. In the multivariate and recent cases, the projected decreases are -4.7 percent and -5.5 percent. When it comes to a 30-year mortality rate freeze all regions face a GDP decline in GDP. SSA suffers the largest GDP decline, namely 13.8 percent. The explanation here is simple. Mortality will decline in all regions over time according to the UN. Delaying this process for three decades leaves a smaller workforce in each region in 2100 than would otherwise be the case.

Our fifth sensitivity analysis is increasing state pensions by 30 percent in all regions. This produces standard crowding out and global output. By 2100, global GDP is 7.8–9.2 percent less than in the baseline scenario depending on catch-up growth assumptions. In addition to reducing world production, this counterfactual is fiscally challenging for regions with older populations and higher initial levels of debt relative to GDP, including the United States.

Table 12's last two scenarios entail corporate tax increases of in the United States and China show small negative effect on the economy of the country that raises the tax rate, as capital begins to flow to other regions.

Table 12: GDP Shares in 2100, Alternative Scenarios

(percent)

	USA	WEU	JKSH	CHI	IND	RUS	BRA	UK	CAN	MENA	MEX	SAF	SAP	SLA	SSA	SOV	EEU	Total
Univariate Growth Rates																		
Baseline	12.3	11.9	3.5	27.0	16.2	1.1	1.3	1.6	1.9	8.3	0.8	0.4	7.4	1.3	3.7	0.9	0.2	100.0
Automation	12.4	12.0	3.5	27.5	17.1	1.1	1.3	1.7	1.9	7.8	0.7	0.4	7.1	1.2	3.2	0.9	0.2	105.5
Fixed Fertility	10.2	9.0	2.4	20.5	20.1	0.9	1.3	1.5	1.6	12.5	0.9	0.5	8.7	1.6	6.9	1.2	0.2	108.8
Fixed Mortality	12.5	12.1	3.7	27.5	15.6	1.1	1.3	1.7	2.0	8.1	0.8	0.4	7.4	1.3	3.3	0.9	0.2	95.8
Pension	12.0	11.7	3.4	26.2	17.4	1.1	1.3	1.6	1.9	8.4	0.8	0.4	7.5	1.4	3.8	0.9	0.2	92.2
Corp. Tax Rise US	12.0	11.9	3.6	27.1	16.2	1.1	1.3	1.7	1.9	8.4	0.8	0.4	7.4	1.3	3.7	0.9	0.2	99.8
Corp. Tax Rise CHI	12.3	11.9	3.6	26.6	16.3	1.1	1.4	1.7	1.9	8.4	0.8	0.4	7.4	1.4	3.7	0.9	0.2	99.7
Multivariate Growth Rates																		
Baseline	18.1	10.8	3.1	7.8	8.0	1.9	2.1	2.4	3.0	9.9	2.1	0.8	7.0	4.2	17.5	0.9	0.4	100.0
Automation	19.1	11.0	3.1	7.5	7.6	1.9	2.1	2.6	3.1	9.6	2.2	0.8	6.9	4.2	17.0	0.9	0.4	99.6
Fixed Fertility	12.3	6.7	1.7	5.1	8.5	1.3	1.7	1.8	2.0	12.9	2.3	0.9	7.2	4.5	29.8	1.0	0.3	117.7
Fixed Mortality	18.8	11.2	3.2	8.0	7.9	1.9	2.1	2.6	3.1	9.8	2.1	0.8	7.2	4.2	15.8	0.9	0.4	95.3
Pension	17.6	10.5	3.0	7.8	8.0	1.9	2.1	2.4	2.8	10.1	2.2	0.8	7.1	4.3	18.0	0.9	0.4	91.9
Corp. Tax Rise US	17.4	10.8	3.1	7.8	8.1	1.9	2.1	2.5	3.0	10.0	2.1	0.8	7.1	4.2	17.6	0.9	0.4	99.2
Corp. Tax Rise CHI	18.2	10.8	3.1	7.5	8.0	1.9	2.1	2.5	3.0	9.9	2.1	0.8	7.1	4.2	17.5	0.9	0.4	99.6
Recent Growth Rates																		
Baseline	10.0	4.8	1.6	22.2	33.8	2.2	0.4	1.0	1.2	8.4	0.4	0.3	6.0	0.9	3.7	2.4	0.8	100.0
Automation	10.1	4.7	1.6	22.6	34.5	2.3	0.4	1.0	1.2	8.0	0.3	0.2	5.8	0.8	3.3	2.5	0.8	106.5
Fixed Fertility	7.6	3.4	1.0	15.2	39.1	1.7	0.4	0.8	1.0	11.8	0.4	0.3	6.5	0.9	6.5	2.9	0.6	117.0
Fixed Mortality	10.3	5.0	1.7	22.8	32.8	2.2	0.4	1.0	1.3	8.3	0.4	0.2	6.0	0.9	3.4	2.5	0.8	94.6
Pension	10.0	4.8	1.6	21.1	33.9	2.3	0.4	1.0	1.2	8.7	0.4	0.3	6.1	0.9	3.9	2.5	0.9	90.8
Corp. Tax Rise US	9.8	4.8	1.6	22.2	33.8	2.2	0.4	1.0	1.2	8.4	0.4	0.3	6.0	0.9	3.8	2.4	0.8	99.8
Corp. Tax Rise CHI	10.0	4.8	1.6	22.0	33.8	2.2	0.4	1.0	1.2	8.4	0.4	0.3	6.0	0.9	3.8	2.4	0.8	99.7

6. Conclusion

This paper develops the Global Gaidar Model (GGM) to study key questions about global economic growth. The most important of these is how global economic power will evolve over the next 100 years. In particular, will the US remain the world's economic hegemon or will the economic baton pass to China or some other region?

The GGM is a dynamic OLG CGE model in which agents, have children, can live to age 100, have CES utility for consumption and leisure, receive inheritances, die randomly in accordance with projected region-specific mortality rates, leave unintended bequests, and rationally anticipate all future changes in factor prices and fiscal variables. Essentially all of the world's countries are combined into the model's 17 large regions. The GGM features global, life-cycle, and region-specific productivity catch-up. There are also high- and low-skilled worker groups as well as catch-up (relative to the US level) labor-productivity growth, which can be negative. The GGM is carefully calibrated to a) UN projected demographics, specifically year-, region-, and cohort-specific birth rates, mortality rates, and net immigration rates and b) IMF fiscal data. Simulating the model provides a picture of the global economic transition and the degree to which region-specific living standards will converge. By modifying particular factors, holding others fixed, the model permits controlled study of sources of global economic growth.

Region-specific productivity catch-up is, we find, the main determinant of future economic power with potential demographic change representing the second biggest factor. Automation and fiscal policy all play second fiddle to these forces. Short of a near-term, sustained, and substantial drop in China's and India's catch-up rates, which some highly leading econometricians predict, this is Asia's economic century with China or India rapidly becoming the world's economic kingpin and the other taking second place.

Under what we take as the most plausible productivity growth scenario, dubbed univarite, China will, in 80 years, account for 27 percent of world output with India producing 16 percent. The US, WEU plus the UK, and JKSH will account for roughly 12 percent, 14 percent, and 4 percent of global GDP, respectively. That's 30 percent collectively. In 2017, China accounted for 17 percent of world output, whereas the US, WEU, UK, and JSKSH jointly produced 43 percent. In short, our projections indicate that China's GDP will go from significantly lagging the collective West to parity with it. India, the largest remaining region in 2100, may play a decisive role in the balance between them.

Our preferred univariate catch-up productivity growth assumptions produce convergence in living standards across many of the world's regions. But major regional living-standard inequality persists through time. Labor productivity differentials are the explanation. Sub-Saharan Africa's 2100 labor productivity is only 7 percent of the US value – not much higher than its 5 percent value in 2017. India, in 2100, is 35 percent as productive as the US. This is far above the 7 percent 2017 figure. But it's miles away from the US, Chinese, and WEU levels. This indicates India's potential to become an even larger economic force through time.

Finally, our model provides a warning to regions, including the US and China, that will come under major economic stress due to the interaction of deficit/pay-go-financed fiscal policies and population aging. Unless these regions can limit fiscal outlays, they face dramatically higher future average and marginal tax rates. This could limit labor supply, induce tax avoidance and evasion, and promote emigration, particularly of high-skilled workers.

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Appendix Table 1: The Global Gaidar Model's Regions

Notation	Region	Countries
US	United States	United States
UK	United Kingdom	United Kingdom
CHI	China	China
IND	India	India
BRA	Brazil	Brazil
MEX	Mexico	Mexico
SAF	South Africa	South Africa
RUS	Russia	Russia
JKSH	JKSH	Japan, Korea, Rep., Singapore, Hong Kong
CAN	CAN	Australia, Canada, New Zealand
WEU	Western Europe	Austria, Belgium, Switzerland, Cyprus, Czech Republic, Germany, Denmark, Spain, Estonia, Finland, France, Greece, Croatia, Hungary, Ireland, Iceland, Israel, Italy, Lithuania, Luxembourg, Latvia, Malta, Netherlands, Norway, Poland, Portugal, Slovak Republic, Slovenia, Sweden
SLA	Latin America and Caribbean	Argentina, Bolivia, Chile, Colombia, Ecuador, Peru, Paraguay, Uruguay, Venezuela
SAP	South Asia (IDA and IBRD)	Bangladesh, Fiji, Indonesia, Cambodia, Sri Lanka, Myanmar, Malaysia, Nepal, Philippines, Thailand, Vietnam, Taiwan Province of China
MENA	Middle East and North Africa	Afghanistan, United Arab Emirates, Bahrain, Algeria, Egypt, Arab Rep., Ethiopia, Iran, Islamic Rep., Iraq, Jordan, Kuwait, Lebanon, Morocco, Mali, Oman, Pakistan, Qatar, Saudi Arabia, Syrian Arab Republic, Tunisia, Turkey, Yemen, Rep.
SSA	Sub-Saharan Africa	Nigeria, Rwanda, Sudan, Senegal, Sierra Leone, South Sudan, Swaziland, Togo, Tonga, Tanzania, Uganda, Zambia, Zimbabwe
SOV	Europe and Central Asia	Armenia, Azerbaijan, Georgia, Kazakhstan, Kyrgyz Republic, Mongolia, Tajikistan, Turkmenistan, Uzbekistan
EEU	Easern Europe	Albania, Bosnia and Herzegovina, Belarus, Bulgaria, Macedonia, FYR, Moldova, Montenegro, Romania, Serbia, Ukraine, Kosovo

Appendix Table 2: U.N. and GGM Population Projections

Total Population (millions)

	US		**WEU**		**JKSH**		**CHI**		**IND**		**RUS**		**BRA**		**UK**		**CAN**	
	2017	**2100**	**2017**	**2100**	**2017**	**2100**	**2017**	**2100**	**2017**	**2100**	**2017**	**2100**	**2017**	**2100**	**2017**	**2100**	**2017**	**2100**
Model	321.9	443.6	460.6	409.2	189.8	132.8	1397.8	986.2	1329.4	1473.0	142.1	121.2	207.9	183.5	65.6	79.8	65.3	98.6
Official	324.5	446.5	465.4	415.5	191.6	135.4	1409.4	1017.0	1339.3	1514.9	144.2	123.9	209.3	189.0	66.2	80.7	65.8	99.2

	EEU		**MENA**		**MEX**		**SAF**		**SAP**		**SLA**		**SOV**		**SSA**	
	2017	**2100**	**2017**	**2100**	**2017**	**2100**	**2017**	**2100**	**2017**	**2100**	**2017**	**2100**	**2017**	**2100**	**2017**	**2100**
Model	72.6	46.1	901.5	1697.1	128.5	146.6	56.1	74.6	799.0	902.6	288.5	348.5	89.9	115.4	743.0	3206.5
Official	73.6	47.4	907.1	1724.2	129.1	150.7	56.7	76.4	804.4	926.0	290.4	356.9	90.6	118.3	748.8	3199.8

Appendix Table 3: U.N. and GGM Fertility Rates

UN Fertility Rate (Children per Woman)

	US		**WEU**		**JKSH**		**CHI**		**IND**		**RUS**		**BRA**		**UK**		**CAN**	
	2017	**2100**	**2017**	**2100**	**2017**	**2100**	**2017**	**2100**	**2017**	**2100**	**2017**	**2100**	**2017**	**2100**	**2017**	**2100**	**2017**	**2100**
Model	1.86	1.86	1.56	1.77	1.38	1.73	1.53	1.69	2.20	1.47	1.69	1.81	1.69	1.66	1.85	1.80	1.69	1.75
Official	1.86	1.86	1.56	1.77	1.38	1.73	1.53	1.69	2.20	1.47	1.69	1.81	1.69	1.66	1.85	1.80	1.69	1.75

	MENA		**MEX**		**SAF**		**SAP**		**SLA**		**SOV**		**SSA**		**EEU**	
	2017	**2100**	**2017**	**2100**	**2017**	**2100**	**2017**	**2100**	**2017**	**2100**	**2017**	**2100**	**2017**	**2100**	**2017**	**2100**
Model	3.04	1.59	2.12	1.67	2.37	1.42	2.20	1.64	2.25	1.64	2.40	1.67	5.09	1.52	1.50	1.74
Official	3.04	1.59	2.12	1.67	2.37	1.42	2.20	1.64	2.25	1.64	2.40	1.67	5.09	1.52	1.50	1.74

Appendix Table 4: U.N. and GGM Age Distributions

Model Age Structure (Percent of Total Population)

		US		**WEU**		**JKSH**		**CHI**		**IND**		**RUS**		**BRA**		**UK**		**CAN**	
		2017	**2100**	**2017**	**2100**	**2017**	**2100**	**2017**	**2100**	**2017**	**2100**	**2017**	**2100**	**2017**	**2100**	**2017**	**2100**	**2017**	**2100**
0-9	Model	12.6	10.8	10.2	9.6	8.7	9.1	12.0	9.3	18.4	9.9	12.5	11.0	14.2	9.0	12.3	10.0	11.8	10.0
	Official	12.5	10.7	10.1	9.5	8.6	9.2	12.0	8.9	18.3	9.8	12.4	10.8	14.2	8.9	12.1	9.9	11.7	9.8
10-19	Model	13.1	10.9	10.5	9.9	9.5	9.3	11.4	9.7	18.9	10.5	9.8	11.4	15.8	9.5	11.3	10.2	11.6	10.4
	Official	13.0	10.8	10.4	9.8	9.4	9.7	11.3	9.2	18.8	10.4	9.6	11.4	15.7	9.4	11.1	10.2	11.5	10.3
20-29	Model	14.2	11.2	11.7	10.4	11.1	9.7	14.9	10.3	17.6	11.1	13.2	12.0	16.6	10.0	13.0	10.8	13.8	10.8
	Official	14.1	11.1	11.6	10.3	11.0	9.6	14.8	10.2	17.5	11.0	13.1	11.8	16.5	9.9	12.8	10.6	13.7	10.7
30-39	Model	13.2	11.5	13.3	10.8	13.0	10.3	15.2	10.6	15.3	11.7	16.6	11.7	16.5	10.5	13.4	11.0	13.9	11.2
	Official	13.1	11.4	13.2	10.7	12.9	10.2	15.1	10.4	15.2	11.6	16.4	11.4	16.4	10.4	13.3	10.9	13.8	11.0
40-49	Model	12.5	11.6	14.5	11.2	15.4	10.8	16.6	11.2	11.9	12.4	13.6	12.1	13.5	11.1	13.2	11.3	13.1	11.5
	Official	12.5	11.5	14.4	11.1	15.3	11.8	16.5	10.7	11.1	12.3	13.4	12.2	13.5	11.0	13.1	11.3	13.1	11.4
50-59	Model	13.4	11.4	14.3	11.5	13.8	11.1	14.2	12.1	9.0	12.9	14.1	12.8	11.0	11.7	13.5	11.6	13.8	11.5
	Official	13.3	11.2	14.2	11.4	13.7	10.9	14.1	11.9	9.0	12.7	14.1	12.6	11.0	11.5	13.5	11.5	13.8	11.4
60-69	Model	11.2	11.1	12.0	11.5	12.8	11.5	9.9	12.2	5.7	12.8	11.5	11.0	7.2	12.2	10.8	11.2	11.2	11.1
	Official	11.2	11.0	12.0	11.3	12.8	11.4	9.9	11.9	5.8	12.7	11.6	10.8	7.2	12.0	10.8	11.0	11.2	11.0
70-100	Model	9.8	21.5	13.4	25.1	15.7	28.2	5.9	24.7	3.3	18.8	8.7	18.1	5.2	26.2	12.6	23.9	10.6	23.6
	Official	10.3	22.2	14.0	26.0	16.3	29.1	6.3	25.6	3.6	19.5	9.3	19.0	5.4	27.0	13.2	24.7	11.1	24.4

		MENA		**MEX**		**SAF**		**SAP**		**SLA**		**SOV**		**SSA**		**EEU**	
		2017	**2100**	**2017**	**2100**	**2017**	**2100**	**2017**	**2100**	**2017**	**2100**	**2017**	**2100**	**2017**	**2100**	**2017**	**2100**
0-9	Model	23.1	11.4	17.8	9.1	19.8	10.8	18.0	10.2	18.0	9.7	20.0	10.7	31.3	15.0	11.0	9.9
	Official	23.1	11.4	17.7	9.0	19.7	10.7	17.9	10.1	17.9	9.6	20.0	10.5	31.2	15.0	10.8	9.8
10-19	Model	19.4	11.9	18.1	9.5	18.5	11.3	17.8	10.7	17.8	10.2	15.6	11.1	23.3	15.0	10.1	10.5
	Official	19.3	11.8	18.0	9.5	18.3	11.2	17.7	10.6	17.7	10.1	15.5	11.1	23.2	14.9	9.9	10.5
20-29	Model	17.6	12.3	17.3	10.0	18.3	11.9	17.2	11.1	17.1	10.6	18.2	11.7	16.6	14.6	13.5	11.0
	Official	17.5	12.2	17.3	9.9	18.1	11.8	17.1	11.0	17.0	10.5	18.1	11.7	16.5	14.5	13.3	10.9
30-39	Model	15.1	12.5	15.2	10.5	16.0	12.3	15.4	11.5	14.8	11.1	15.5	12.0	12.0	13.9	15.9	11.1
	Official	15.0	12.4	15.1	10.4	16.0	12.2	15.3	11.4	14.8	11.0	15.4	11.8	11.9	13.8	15.7	10.9
40-49	Model	10.6	12.6	13.2	11.1	11.3	12.7	12.8	12.0	11.9	11.6	11.7	12.3	7.8	12.8	13.9	11.7
	Official	10.6	12.5	13.2	11.0	11.3	12.6	12.8	11.9	11.8	11.5	11.6	12.2	7.8	12.7	13.8	11.7
50-59	Model	7.3	12.5	8.6	11.7	8.1	12.8	9.8	12.3	9.4	12.1	10.1	12.9	4.8	11.2	14.0	12.5
	Official	7.3	12.4	8.6	11.6	8.1	12.7	9.8	12.2	9.4	11.9	10.1	12.8	4.8	11.1	13.9	12.3
60-69	Model	4.3	11.4	5.6	12.2	5.1	11.9	5.6	12.1	6.2	12.1	5.6	11.9	2.8	9.0	11.8	11.7
	Official	4.4	11.3	5.6	12.0	5.2	11.8	5.6	11.9	6.3	12.0	5.7	11.7	2.9	9.0	11.9	11.5
70-100	Model	2.7	15.5	4.3	25.9	2.9	16.2	3.5	20.1	4.8	22.7	3.3	17.5	1.5	8.5	9.9	21.7
	Official	2.9	16.1	4.5	26.6	3.2	16.9	3.8	20.8	5.1	23.4	3.6	18.2	1.6	8.9	10.6	22.5

Appendix Table 5: IMF and GGM 2017 Macro Indicators

	US	**WEU**	**JKSH**	**CHI**	**IND**	**RUS**	**BRA**	**UK**	**CAN**
Gross Domestic Product (PPP) as share of US									
Data	100.0	104.3	42.3	101.4	42.4	19.5	15.4	15.5	16.4
Model	100.0	104.3	42.2	101.3	42.4	19.5	15.4	15.6	16.4
Private Consumption (percent of GDP)									
Data	68.2	53.4	53.3	39.0	58.9	52.9	64.5	64.5	57.3
Model	68.2	53.4	53.2	39.0	58.9	52.9	64.5	64.7	57.0
Government Consumption (Percent of GDP)									
Data	14.1	20.3	17.8	14.6	10.8	18.2	20.2	18.7	19.7
Model	14.1	20.4	17.8	14.6	10.8	18.3	20.0	18.9	19.5
Fossil Fuel Rents as percent of GDP									
Data	0.2	0.1	0.0	1.2	1.6	7.3	1.4	1.0	0.5
Model	0.2	0.1	0.0	1.2	1.6	7.3	1.4	1.0	0.5

	MENA	**MEX**	**SAF**	**SAP**	**SLA**	**SOV**	**SSA**	**EEU**
Gross Domestic Product (PPP) as share of US								
Data	52.8	12.6	3.7	40.1	19.6	5.4	13.3	4.7
Model	52.8	12.7	3.7	40.1	19.6	5.4	13.3	4.7
Private Consumption (Percent of GDP)								
Data	55.5	65.3	59.4	59.1	66.8	57.6	70.2	67.3
Model	55.5	65.3	59.6	59.1	66.8	57.6	70.2	67.2
Government Consumption (percent of GDP)								
Data	15.9	11.6	20.9	10.8	14.9	11.9	10.8	18.1
Model	15.9	11.7	21.3	10.8	15.0	11.6	10.8	18.4
Fossil Fuel Rents as Percent of GDP								
Data	9.6	2.8	1.6	1.2	0.8	6.8	2.8	0.1
Model	9.6	2.8	1.6	1.2	0.8	6.8	2.8	0.1

Appendix Table 6: Government Finances in 2017: Model and Real Data

	US		WEU		JKSH		CHI		IND		RUS		BRA	
	Data	Model	Data	Model	Data	Model	Data	Model	Data	Model	Data	Model	Data	Model
Total Expenditures	38.0	37.9	45.9	46.0	34.9	34.8	30.7	30.7	23.0	23.0	36.6	36.8	48.2	48.0
Health	9.3	9.3	6.8	6.8	6.4	6.4	3.0	3.0	1.0	1.0	3.0	3.0	3.8	3.8
Education	6.1	6.0	4.7	4.8	3.5	3.5	3.7	3.7	3.8	3.8	3.5	3.5	6.0	5.9
Purchases of G&S excl. Health and Education	11.1	11.0	13.6	13.7	10.0	10.0	14.6	14.6	7.3	7.4	16.1	16.1	10.4	10.3
Pension Benefits	6.5	6.5	10.1	10.1	8.0	8.0	4.9	4.9	4.3	4.3	8.8	8.8	12.0	12.0
Transfers & Ben Different from Pensions	1.2	1.2	8.9	8.9	5.5	5.5	3.6	3.6	1.6	1.6	4.4	4.4	7.1	7.1
Payment on Debt	3.9	3.9	1.8	1.8	1.5	1.5	0.9	0.9	5.0	5.0	0.9	0.9	9.0	8.9
General Government Revenues	32.1	35.4	44.9	45.2	33.9	34.3	28.3	30.3	14.9	19.3	35.8	36.5	40.0	40.9
Tax Revenues	25.1	28.5	30.7	31.4	23.1	23.9	21.4	23.9	11.4	15.8	21.5	22.1	27.7	28.7
Corporate Tax	2.0	2.0	3.7	3.7	6.3	6.3	5.5	5.5	3.3	3.3	4.1	4.1	4.0	4.0
Consumption Tax	5.2	6.0	13.0	13.4	7.9	8.3	12.5	14.5	5.6	8.6	11.7	12.2	16.6	17.2
Income Tax	18.0	20.5	14.1	14.4	8.9	9.3	3.4	3.9	2.5	3.9	5.6	5.8	7.2	7.5
Non Tax Revenues	6.9	6.9	13.7	13.7	10.4	10.4	6.4	6.4	3.5	3.5	14.3	14.4	12.3	12.3
Social Security Contributions (Pensions)	6.7	6.7	13.6	13.6	10.4	10.4	5.2	5.2	1.9	1.9	7.0	7.0	10.9	10.9
Fossil fuels	0.2	0.2	0.1	0.1	0.0	0.0	1.2	1.2	1.6	1.6	7.3	7.3	1.4	1.4

	UK		CAN		MENA		MEX		SAF		SAP		SLA	
	Data	Model	Data	Model	Data	Model	Data	Model	Data	Model	Data	Model	Data	Model
Total Expenditures	41.2	41.4	38.2	38.0	32.8	32.8	25.5	25.6	42.0	42.7	18.0	18.0	30.3	30.5
Health	7.5	7.5	7.4	7.3	3.9	3.9	2.9	2.9	4.3	4.4	1.3	1.3	4.8	4.8
Education	5.0	5.0	5.3	5.3	3.2	3.2	4.9	5.0	5.6	5.7	2.9	2.9	4.9	5.0
Purchases of G&S excl. Health and Education	10.9	11.0	13.5	13.5	15.9	15.9	7.3	7.4	20.9	21.3	10.7	10.7	14.1	14.2
Pension Benefits	8.3	8.3	4.0	4.0	4.6	4.6	2.1	2.1	1.5	1.5	0.4	0.4	2.1	2.1
Transfers & Ben Different from Pensions	6.8	6.8	5.8	5.8	3.8	3.8	5.4	5.4	5.7	5.9	1.3	1.3	3.5	3.5
Payment on Debt	2.7	2.7	2.1	2.1	1.4	1.4	2.9	2.9	3.9	3.9	1.4	1.4	1.0	1.0
General Government Revenues	38.6	40.0	37.3	36.7	28.9	31.7	22.0	23.4	37.2	39.9	16.3	17.1	24.7	29.7
Tax Revenues	29.6	31.2	34.5	33.8	15.3	17.8	16.7	18.3	35.0	37.7	14.8	15.6	20.4	25.8
Corporate Tax	3.9	3.9	6.1	6.1	1.8	1.8	4.3	4.3	6.9	6.9	4.6	4.6	3.9	3.9
Consumption Tax	12.1	12.8	8.1	7.9	10.7	12.7	7.1	8.0	13.8	15.2	8.4	9.1	10.9	14.6
Income Tax	13.7	14.5	20.2	19.8	2.8	3.3	5.3	6.0	14.3	15.7	1.8	2.0	5.5	7.4
Non Tax Revenues	8.8	8.8	2.9	2.9	14.0	14.0	5.0	5.0	2.2	2.2	1.5	1.5	3.9	3.9
Social Security Contributions (Pensions)	7.8	7.8	2.4	2.4	4.4	4.4	2.2	2.2	0.6	0.6	0.3	0.3	3.1	3.1
Fossil fuels	1.0	1.0	0.5	0.5	9.6	9.6	2.8	2.8	1.6	1.6	1.2	1.2	0.8	0.8

	SOV		SSA		EEU	
	Data	Model	Data	Model	Data	Model
Total Expenditures	25.3	24.9	28.3	28.2	40.0	40.4
Health	2.3	2.2	1.4	1.4	3.9	3.9
Education	3.6	3.5	4.1	4.1	5.6	5.7
Purchases of G&S excl. Health and Education	11.9	11.6	10.8	10.8	13.1	13.3
Pension Benefits	4.0	4.0	2.1	2.1	6.9	6.9
Transfers & Ben Different from Pensions	2.8	2.7	7.4	7.4	7.6	7.7
Payment on Debt	0.8	0.8	2.5	2.5	3.0	3.0
General Government Revenues	23.7	24.3	21.8	25.8	40.1	39.2
Tax Revenues	15.4	15.7	16.7	20.8	31.3	30.9
Corporate Tax	4.0	4.0	3.1	3.1	3.4	3.4
Consumption Tax	8.2	8.5	9.2	11.9	20.7	20.4
Income Tax	3.2	3.3	4.5	5.8	7.2	7.1
Non Tax Revenues	8.7	8.6	5.0	5.0	8.3	8.3
Social Security Contributions (Pensions)	1.9	1.9	2.2	2.2	8.2	8.2
Fossil fuels	6.8	6.8	2.8	2.8	0.1	0.1

Appendix Table 7: Summary of Data Sources and References

	Sources	Used in
Demographics		
Population (Including Projections)	UNP (2017)	Table 2, 4
Fertility	UN (2016a)	Table 3
Immigration	UN (2016b)	Tables 4, 2
Mortality	UN (2016c)	Tables 4, 2
Worker and Person Characteristics		
Worker Shares		ref
Age Productivity Profile		ref
Productivity parameters	Matches GDP as reported by IMF (2018)	Table 9
Delta	Matches Private Consumption percent GDP as reported by IMF (2018)	Tablas 8
Initial Assets Level Total	Credit Swiss Global Wealth Report Global Wealth Report Credit Swiss (2017)	Table 5
Initial Assets Per Person	OECD (2017) and Household Surveys when available	Simulation
Initial Age-Asset Distribution	OECD (2017) and Household Surveys when available	Simulation
Public Sector		
Retirement Age	WB (2016) Reports and Trading Economics (2017)	Table 7
General Government Spending (Grows w/Output) - Number	IMF (2018), IMF (2018), and Article IV Reports	Table 6
Health Spending Age Profile and Disability Spending Per Person (Grows w/Output)	Data constructed using various sources: i) When available reported data by each country to the World Bank or Regional Development Bank; ii) Centers for Medicare and Medicaid Services, Office of the Actuary, National Health Statistics Group; iii) Major Public Health Service Institution, usually called social security institutes. When the latter, we used medical costs and age distribution of government-sponsored beneficiaries	Simulation
Education Expenditures Per Person (Grows w/Output) Education Spending Age Profile	Data constructed using the Annual Approved Budgets, including expenses as primary education, schools, higher education, scholarship programs, training programs sponsored by public sector, senior education programs, etc. When available, first source from World Bank or regional Development Banks reports. Since not all countries had this data available, we captured as much as we could per each country group, paying special attention to the median country in each group.	Simulation
Government Revenue		
Consumption/Income Tax Mix	IMF (2018), IMF (2018), and Article IV Reports	Table 6
Income Tax Progressivity		Simulation
Corporate Tax METR and Rebate	METRs from Mintz and Bazel (2017), when unavailable statutory rates from KPMG (2017)	Table ??
Share of Pensions from Special Pension Tax	WDI World Bank (2017) and IMF Article IV Reports	Simulation
Pension Replacement Rate	Matches Pension Benefits as Percent of GDP as reported in IMF (2018) and WDI World Bank (2017)	Table 7
Pension Contribution Ceiling	OECD, Pension Commissions, and World Bank	Table 7
Debt-to-GDP Level	IMF (2018) and Article IV Reports	Simulation
Oil		
Country Endow Level	Oil flows from WDI World Bank (2017), Stocks from IEA (2016)	Table 5
Share of Country Endow Owned by Gov	Constructed based on WDI World Bank (2017)	Simulation

Appendix Table 8: Parameters Used in Simulations

Capital Share	Low-Skilled Labor Share	High-Skilled Labor Share	Technical Progress	Depreciation Rate	Leisure Preference	Elasticity of Substitution	
						Intertemporal	Intratemporal
α	β_l	β_h	λ	δ_K	ε	γ	ρ
0.35	0.4	0.25	0.0156	0.075	1.5	0.25	0.4