Global Climate Change and its Distributional Impacts

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Abstract:

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Introduction

Climate change has the potential to be the major social and economic challenge over the next century—with the aggregate economic impacts largely overshadowing other major global economic issues such as trade policies and international migration. To put the magnitudes in perspective, a report issued 2006[1] compiled results from 18 models of the global economy that had average carbon emissions at around 10 gigatons in 2025 in the baseline or business-as-usual scenario. The average carbon tax in 2025 to achieve an overall limit on temperature change from these models is $100 per ton of carbon. Thus the revenues from carbon taxes, on a global level, would be around $1 trillion in 2025 and rising over time. Estimates of damages from climate change, though varying widely across studies, range up to 20 percent of GDP, with the mode at around 1-2 percent of GDP [to be verified]. There is also the possibility of tipping points—leading to uncontrollable climate change—such as a sudden release of greenhouse gases (GHG) stored in permafrost, for example, or the collapse of Antarctic ice sheet. Beyond the aggregate effects, the impacts of climate change and policies to mitigate GHG emissions will vary widely across and within countries. Most studies have focused on the cross-country distributional impacts—one of the objectives of this paper is to provide an overview of the within country impacts by linking a global economic model with a global micro-simulation model based on a comprehensive compilation of country-based household surveys.

Summary description of the ENVISAGE model

Introduction

As part of its new program on the economics of climate change, the World Bank is developing a new global dynamic computable general equilibrium (CGE) model specifically designed for assessing the economic impacts of climate change. The model, known as the ENVironmental Impact and Sustainability Applied General Equilibrium Model, or ENVISAGE[2], is a derivative of the World Bank's global trade model known as LINKAGE[3]. The key differences include the following:

- A much more detailed specification of the energy side of the model, with a focus on the substitution of energy with other factors of production and cross-fuel substitution
- Multiple production streams that produce the same output using different technologies (e.g. hydro, nuclear and conventional electricity)
- A consumer demand structure that allows for more complex interactions between energy demand and other consumer demands than the standard top-level utility function[4]
- The ability to introduce new energy sources, e.g. carbon capture and storage, bio-fuels
- A resource depletion module[5]
- An emissions module that is demand and fuel specific
- A climate module that converts atmospheric emissions into radiative forcing and temperature change (relative to 1900)

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1 See Weyant et al 2006.

2 The current full model specification is described in van der Mensbrugghe 2008.

3 The full model specification of LINKAGE is described in van der Mensbrugghe 2006.

4 This is based on a transitions matrix approach—similar to that used in the OECD GREEN model. See Burniaux et al 1992 and van der Mensbrugghe 1994. For the moment the use of this approach is still limited due to lack of sufficient data.

5 Not yet fully developed.

- Multiple mitigation strategies that include carbon taxes, flexible cap and trade regimes, sector- and/or agent-specific exemptions.

Future planned improvements include incorporating other greenhouse gases such as methane (largely based on agricultural production), a more detailed land-use and forestry module, splitting of existing electricity into hydro, nuclear, conventional and other, and the inclusion of additional future technologies such as carbon capture and storage (CSS).

The current version of the model is based on GTAP release 6.2 that has a 2001 base year. The model is solved forward, in recursive fashion, until 2050—originally in steps of 1 year and after 2015 in steps of 5 years. For the purposes of this paper, the analysis ends in 2030 to link up with the income distribution model that has a 2030 terminal year. The country and commodity aggregations are for this study are provided in Annex A.

Model specification

This section describes the main features of the comparative static features of the model ending with a brief description of the dynamic features.

Production, typical to most CGE models, is based on a series of nested CES functions that are intended to represent the substitution and complementarity relations across the different inputs into production.[6] The production nesting in ENVISAGE is somewhat less complex than in the Linkage[7] model—with the exception of the energy bundle—and is closer in technology to the GREEN[8] and GTAP-E[9] models. A top-level nest combines inputs of goods and services (excluding energy) with a value added bundle that includes energy (figure 1). Typically the substitution at this level is assumed to be zero, i.e. non-energy goods and services are used in fixed proportion relative to output. The value added bundle is divided across the various factors of production where it is assumed that capital and energy form a separate bundle. Production in the model is built around a vintage structure with capital divided into *Old* or installed vintages and *New* capital that is capital formed installed at the beginning of the period. This vintage structure allows for variable substitution and complementarity relations across the different inputs where it is typically assumed that substitution elasticities are lower for installed capital than for *New* capital. Thus capital and energy can be complements in the short-run with a zero (or near zero) substitution elasticity assumed for *Old* capital, and substitutes in the long-run with relatively high substitution elasticities on *New* capital. One additional impact of the vintage structure of production is that countries with relatively higher savings and investment rates will tend to have more flexible economies since the share of *New* capital will be higher in the long run.

The energy bundle is disaggregated into different energy sources using an additional suite of CES functions (figure 2). The top-level bundle is composed of electric and non-electric bundles. The latter is decomposed into coal and an oil and gas bundle. And this final bundle is decomposed into

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6 A less-used alternative is flexible functional forms such as the trans-log function.

7 As well, unlike in the Linkage model, all sectors have the same production specification, including the crop and livestock sectors.

8 See Burniaux et al 1992 and van der Mensbrugghe 1994.

9 See Burniaux and Truong 2002.

gas and oil demand. In the base year, these four bundles—electricity, coal, oil and gas[10]—are composed only of their conventional sources, in other words, there are no available backstop or alternative technologies. The backstop technologies are added to the energy mix in the future—at a determined price and with given demand parameters.

All income accrues to a single representative household. Similar to the GTAP model, this household allocates income across three expenditure categories[11]--public and private consumption and savings—using a top-level Cobb-Douglas utility function (figure 3).[12] Private consumption is then allocated across consumer goods using a top-level constant-differences-in-elasticity (CDE) utility function. Consumer goods are differentiated from produced goods and a transition matrix approach is used to combine one or more produced goods to 'make' a consumer good. The transition matrix itself does not assume a fixed technology allowing for substitution across the 'inputs' of the consumer good using a CES technology. The advantage of the transition matrix approach is that it allows for a more realistic modeling of the demand for energy in the household sector. Fuel demand can be combined with a demand for transportation, electricity demand can be combined with a demand for housing and/or other electronics, etc. Moreover, it potentially avoids some problems with many top-level utility functions, such as the Cobb-Douglas or the linear expenditure system (LES), where all goods are gross substitutes. For example, a tax on fuels would induce an increase in the demand for automobiles, rather than the reverse if fuel and automobiles are complements.[13]

The decomposition of the energy bundle in final demand is the same as in production.

The trade block of the model is almost identical to Linkage. Top level (Armington) demand is allocated between goods produced domestically and an aggregate import bundle (figure 4).[14] Unlike GTAP, the Armington allocation is done at the national level rather than by individual agent.[15] The aggregate import bundle is then disaggregated across the various trading partners using an additional CES nest. Domestic production is treated in an analogous fashion using nested constant-elasticity-of-transformation (CET) functions. Aggregate domestic production is allocated to the domestic and an export market. The latter is then further disaggregated across destination export markets.[16] In the goods markets there are R+1 equilibrium prices for each region and commodity where R is the total number of regions—the domestic price of domestically produced goods sold on the domestic market and the world export price for goods sold to each one of the trading partners.[17]

There are five factors of production. Skilled and unskilled labor are partially or fully mobile across sectors. The model allows for some labor market segmentation between rural (agricultural) and

10 Because of the definition of the GTAP data the oil bundle is composed of crude and refined oil and the gas bundle is composed of both natural gas and distributed gas.

11 See Hertel 1997.

12 The ENVISAGE model uses the revised version of the GTAP demand structure as described in McDougall 2003.

13 Though, one interpretation of this is that consumers purchase more efficient and more expensive cars, such as hybrids.

14 The model does allow for the introduction of homogeneous traded goods.

15 The model does potentially allow for an agent-based Armington allocation but is rarely used to limit the model size and complexity.

16 Note that the default transformation elasticity is infinity so that the law-of-one price holds across all markets of destination including the domestic market.

17 The model has a mix of countries and regions and for countries there are no intra-country exports in which case the number of markets is R and not R+1. In the case of regions—for example the EU—, there is intra-regional trade that is treated as an additional export market

urban activities that induces a wage premium for urban workers. Wages clear labor markets within each segment—and labor is fully mobile within each segment. Land is modeled using a CET transformation function that can be varied from sector-specific to fully mobile. The aggregate land supply function is an upward sloping constant elasticity function. Market clearing conditions are assumed for the land market. The natural resource sectors, in particular coal, oil and natural gas production, are associated with a sector specific factor, i.e. the natural resource base, or the reserves. These are (for the moment) modeled using upward sloping supply curves. There is a sector-specific price that clears the market for the resource.

Due to the vintage structure, market clearing of the capital market is somewhat more complex. In any given period, the aggregate capital stock is fixed and is equated to the depreciated value of the previous capital stock plus the previous period's level of investment. The latter is equated with *New* capital and the former with *Old* capital. *New* capital is allocated across sectors so as to equalize the rate of return. If all sectors are expanding, i.e. all sectors are demanding *New* capital to meet demand, than the return on installed capital is assumed to equal the return on *New* capital. Contracting sectors have a surplus of *Old* capital, which will be added to *New* capital under the assumption that the most mobile of the installed capital will be released first—for example transportation equipment, office space, computers, etc. The remaining *Old* capital faces an upward sloping supply curve that combined with sectoral demand for capital determines the rate of return that is always less than the economy-wide rate of return of *New* capital.

The standard macro closure in the baseline has government expenditures as a share of GDP fixed at base year levels, a demographically determined savings function that determines the allocation of private expenditures between consumer demand and domestic investment, and the latter is adjusted by a fixed level of foreign saving[18], i.e. investment is savings driven. The model numéraire is defined as the manufactured export price index of the high-income countries.

The climate module replicates that described in Nordhaus and Boyer 2000 and Nordhaus 2007. Carbon (or CO_2) emissions emanate from the consumption of fossil fuels in both production and final demand activities.[19] These are emitted into the atmosphere. A transition matrix approach is used to allocate the stock and flows of carbon across three sinks—the atmosphere and the upper and deep oceans. The initial flow, i.e. the human generated carbon emissions are 100 percent absorbed by the atmosphere, but over time, part of the stock of carbon in the atmosphere is absorbed by the shallow ocean and eventually by the deep ocean. Over (a long period of) time, in the absence of new emissions, a new carbon equilibrium would be obtained across the three sinks.

The key to climate change is the increase of atmospheric concentration of carbon (and other greenhouse gases). This leads to an increase in so-called radiative forcing whereby more of the sun's energy is absorbed in the atmosphere and leads to rising temperatures. The model includes a further dynamic whereby atmospheric and ocean temperatures also interact.

Finally, a feedback exists between the change in atmospheric temperature and economic activity, using damage functions. These latter represent sector- and region-specific productivity shocks that are calibrated to estimates available in a limited but growing literature. Hence a rise in atmospheric

18 Normally fixed at base year levels such that it declines (towards 0) as a share of GDP.

19 The emissions module adjusts for the transformation of fossil fuels in certain key sectors, for example petroleum refining.

temperature of 2.5°C (relative to 1900), might lead to a decline in agricultural productivity of anywhere between 0 and 40 percent depending on the crop and region.[20] Some regions may benefit, at least initially, from global warming, such as those lying in the upper latitudes (e.g. Canada and Russia).[21]

The model dynamics are pretty straightforward as the model is recursive dynamic. Labor force and population growth rates are exogenous and consistent with the UN's medium variant population forecast. The growth in the labor force is equated to the growth of the working age population, i.e. the population aged between 15 and 64. The allocation between rural and urban segments is determined by the migration assumptions. [Should we say something about the skilled/unskilled split?]. Land and natural resources are determined by a fixed upward sloping supply curve.[22] Capital formation is driven by the demographics-based savings function and the evolution of the price of capital goods (or the cost of investment).

The other key factor in dynamics regards the assumption on productivity. The baseline takes a sectoral approach that divides each economy into three broad segments. The agricultural sector is assumed to have an exogenous and factor-neutral productivity improvement that is based on existing estimates of between 1.5 and 2.5 percent per annum. This is not differentiated across sectors nor across regions, though could be with additional information. The remaining sectors are divided into two—manufacturing and services. In these sectors, productivity is assumed to be exclusively labor-augmenting. There is a wedge inserted between manufacturing and services productivity with the assumption that manufacturing productivity is higher than in services. The default wedge is 2 percentage points. Hence if labor productivity is 2 percent in services it is 4 percent in manufacturing. In the baseline, labor productivity is calibrated to achieve an exogenous path for the growth of real GDP through 2015 and is held fixed at the 2015 level afterwards.

Finally, it is assumed that energy efficiency, otherwise known as the autonomous energy efficiency improvement (AEEI) parameter, improves at an exogenous rate—currently set at 1 percent per annum in all regions and for all activities.

Overview of the Global Income Distribution Dynamics (GIDD) model

The distributional analysis in this paper has been carried out with the World Bank's GIDD model, which generalizes the existing CGE-microsimulation methodologies—e.g., Bourguignon, Robillard and Robinson (2003); Chen and Ravallion (2003); and Bussolo et al (2008)—at the global level. The starting point is the global income distribution in 2000, assembled using data from household surveys for 73 developing countries and data on income groups (usually vintiles) for 25 high income and 22 developing countries. The final sample covers more than 90 percent of the world's population (see Annex B for a country coverage table). The counterfactual income distribution is obtained by capturing three major changes in the structure of the population and the economy: (a) change in the age and skill composition of the population, (b) change in the allocation of workers across sectors in the economy, and (c) change in returns to labor by skill and occupation. Although

20 Cline 2007 has a comprehensive set of estimates for climate change impacts on agriculture.

21 There are additional issues related to agricultural productivity and its link to climate change including water availability and the role of carbon fertilization.

22 A future version of the model will include a resource depletion module for natural resources.

in reality these changes take place simultaneously, in the GIDD framework they are accommodated in a sequential fashion.

The conceptual framework of the GIDD is depicted in Figure . The expected changes in population structure by age (upper left part of Figure) are taken as exogenous from the population projections provided by the World Bank's Development Data Group. Therefore, we assume that fertility decisions and mortality rates are determined outside the model. The change in shares of the population by education groups incorporates the expected demographic changes (linking arrow from top left box to top right box in Figure). Next, new sets of population shares by age and education subgroups are computed and household sampling weights are re-scaled according to the demographic and educational changes above (larger box in the middle of Figure). The impact of changes in the demographic structure on labor supply (by skill level) is incorporated into the CGE model, which then provides a set of link variables for the microsimulation: overall economic growth, growth in relative incomes by skill and sector, and the movement of labor between agricultural and non-agricultural activities. The final distribution is obtained by applying the changes in these link variables to the re-weighted household survey (bottom link in Figure).[23]

The sequential changes described above reshape national income distribution under a set of strong assumptions. In particular, income inequality within population subgroups formed by age, skills, and sector of employment is assumed to be constant over the period. Moreover, data limitations affect estimates of the initial inequality and its evolution. Although consumption expenditure is a more reliable welfare measure than income, and its distribution is normally more equal than the distribution of income, consumption data are not available for all countries' surveys. To get a global picture, the present study had to include countries for which only income data were available.

Finally, measurement errors implicit in purchasing power parity exchange rates, which have been used to convert local currency units, also affect comparability across countries. The resulting income distribution should thus not be seen as a forecast of what the future distribution might look like; instead it should be interpreted as the result of an exercise that captures the ceteris paribus distributional effect of demographic, sectoral, and economic changes. Although the results of this exercise provide a good starting point for debating potential policy trade-offs, they should not be used as the basis for detailed policy blueprints.

Three scenarios

This section describes some of the key findings from three scenarios that are derived with the use of the ENVISAGE model. The first scenario is a standard business-as-usual (BaU) scenario, alternatively referred to as the reference or baseline scenario. The key growth factors, mentioned above, include labor and population growth, capital accumulation and productivity. It is referred to as the BaU scenario because it assumes that by and large all existing policies remain in place, particularly those linked to energy prices and investment.[24] The link between temperature change and agricultural productivity is included in the BaU scenario. The second scenario removes agricultural damages thus providing a measure of how important these might be on a regional and global scale. All else in the BaUND scenario is exactly as in the BaU. The third scenario is a

23 See Annex B for a detailed description of the GIDD, including the mathematical statement.

24 Future baseline scenarios will also include endogenous adaptation of new energy technologies, to the extent that they become competitive with their conventional counterparts.

mitigation scenario. It assumes full participation and an efficient mechanism for reducing emissions, i.e. a globally applied uniform tax on carbon emissions. In this scenario, all tax revenues are recycled internally, i.e. there is no cap and trade system that could lead to a re-allocation of tax revenues across countries.[25]

Business-as-Usual scenario (BaU)

The drivers of future emissions of CO_2 are population and economic growth. If growth is purely homothetic, i.e. all sectors and inputs grow at the same rate, then the growth in emissions will equate to the growth in the economy. However, there are a number of channels that affect the overall growth in emissions. One oft-used formula to explain emissions in an economy is the so-called Kaya identity[26]:

$$(1) \qquad EMI = \frac{EMI}{FFC} \cdot \frac{FFC}{PEC} \cdot \frac{PEC}{GDP} \cdot \frac{GDP}{POP} . POP$$

- The formula links emissions to four "intensities" and population. The four intensities are:
- Emissions (*EMI*) per fossil fuel consumption (*FFC*)—a switch to natural gas from oil or coal, for example, can reduce this intensity
- Fossil fuel consumption per total primary energy demand (*PEC*)—a switch to hydro, nuclear or renewable electricity generation can reduce this intensity
- Primary energy demand per unit of GDP—this intensity can be reduced through improved energy efficiency, for example more efficient automobiles or power generation, and/or through structural shifts in the economy, for example away from energy intensive manufacturing towards services
- GDP per capita (*POP*)—which is generally growing globally, and particularly quick over the last decade in developing countries.

Our baseline scenario has population growth slowing down, but nonetheless an increase in population from a present-day estimate of 6.5 billion persons, to somewhere around 8.8 billion in 2050 (figure 6). Virtually 100 percent of the increase between 2005 and 2050 is accounted for by population growth in developing countries, with an estimated slight decrease for high-income countries—raising the developing country share from present-day 83 percent to nearly 88 percent in 2050.[27] The growth rate declines sharply, from around 1.2 percent per annum to less than 0.4 percent and will eventually stabilize at 0 under the UN's medium term population scenario that assumes fertility rates converge towards replacement rates in all countries.[28]

Global growth is assumed to peak around 2010 at around 3.4 percent per annum and slowly converge towards 2.3-2.4 percent per annum by 2050 (figure 7). Growth is highly differentiated between high-income and developing countries. There is a wide difference between high-income and developing country with the growth wedge at around 4 percentage points initially and slowly

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25 We had hoped to undertake a fourth scenario that would lead to the same emissions reduction as in the full participation mitigation scenario, but convergence proved difficult in the absence of alternative energy technologies.

26 See for example Raupach et al 2007 and Bacon and Bhattacharya 2007.

27 Assuming of course a static definition of which countries are classified as high-income and which are classified as developing.

28 This implies, notably, that fertility rates in a broad swath of high-income countries will eventually rise as they are considerably below replacement rate today.

declining to around 2.6 percentage points towards the end of the scenario. This takes the global economy from around $35 trillion in 2005 to $109 trillion in 2050—translating into 2.6 percent growth on average (compounded annually). Despite the higher growth in developing countries, there would remain a large gap in relative incomes—even adjusted for purchasing parity differences (figure 8). In 2050, under this scenario, average per capita incomes in developed countries rise to over $45,000 (at market exchange rates, MER), whereas the average developing country income would be somewhere around $7,600. The overall ratio of per capita incomes between the high-income countries and developing countries falls from 17.7 in 2005 to 6.1—a very substantial fall.

There is little evidence of decarbonization in the baseline scenario. Carbon emissions rise from 7 gigatons (GtC) in 2005 to nearly 24 GtC in 2050—actually slightly more rapid than GDP growth on average (figure 9)—this in spite of an autonomous rate of energy efficiency improvement of 1 per cent per annum globally. This paper does not include a full decomposition of energy/emissions growth but some of the channels include a relatively benign price scenario for fossil fuels—particularly coal[29], rapid industrialization, and the fact that energy efficiency improvements also lower the price of energy, all else equal, that counteracts to some extent the improvements in efficiency.[30]

As in growth, there is a wide degree of difference in the growth rates of emissions between developed and developing countries. Developed countries would account for only 6 percent of the incremental emissions between 2005 and 2050, or less than 1 GtC out of the total increase of 16.9 GtC. Whereas both regions are responsible for roughly 50 percent of the emissions in 2005, by 2050, the preponderance of emissions, over 80 percent, will be sourced in developing countries.[31] The key finding to come out of this baseline scenario is that even if emissions in developed countries fall to zero, any scenario that has developing countries using energy as in the past or currently, coupled with relatively high economic growth rates, global emissions will increase relatively rapidly as will atmospheric concentrations of greenhouse gases.[32]

Similar to incomes, there is an existing wide discrepancy in per capita carbon emissions (figure 10). The average person in high-income countries emits almost three times the amount of carbon annually in 2005 (over 3 tons), compared to just over 1 ton on average across the world. Not surprisingly, given the discussion above, this wedge falls sharply by 2050—and China could in fact surpass high-income per capita emissions some time between 2035 and 2040 under this baseline, and be well above by 2050. High income growth, low coal prices, continued industrialization combine to generate this result, albeit in the absence of policies to raise coal prices and/or develop sources of 'clean' energy.

The baseline scenario leads to a carbon concentration level that rises from around 390 parts per million (ppm) in 2001 to 560 ppm in 2050—clearly well above any stabilization scenario of 450 ppm promoted by some as an upper limit to avoid severe damages, or the more modest target of 550 ppm that many others perceive as a threshold not to surpass (figure 11). As worrisome as the

29 The oil price is calibrated to the recent trends, but the long term price is assumed to decline from current highs.

30 At this stage, the model also does not have a full accounting of non-fossil fuel based energies such as nuclear, hydro and renewables that would most likely have an impact on baseline emissions.

31 These percentages will not necessarily lineup with who is responsible for the given stock of CO_2 in the atmosphere. For that, we would need to couple the model results with a historical time series on CO_2 emissions.

32 Note, furthermore, that the current version of the model excludes carbon emissions from non-energy sources, such as deforestation and agricultural practices, as well as other greenhouse gas emissions such as methane.

overall concentration level in 2050, it is clear from the chart that the path is far from a stabilization scenario with concentrations likely to continue increasing well beyond 2050. Of course the true objective is the overall rise in temperature which in our baseline and given climate sensitivity rises to 1.75 ºC (relative to 1900 levels) and by overall a full ºC relative to 2001—driven by an increase in radiative forcing. This is in the range of estimates produced by IPCC 2007, though perhaps somewhat on the low end [need to verify].

Business-as-Usual with no damages scenario (BaUND)

Distributional impacts of Climate Change Damages and Mitigation Policies

Under the business-as-usual scenario developed in the previous section, the global income distribution is likely to undergo major changes in the next 40 years. As developing countries exhibit per capita growth rates consistently above those of high-income nations, global inequality is likely to fall by approximately [5] Gini points. Furthermore, higher-than-average (relative to the overall developing world) growth in initially poorer regions like East and South Asia is likely to virtually eliminate poverty at the US$2 per day (PPP) poverty line (Table 1). The only regions where poverty remains above 1 percent of total population are Latin America and Sub-Saharan Africa: the former due to relatively slow projected growth rates over the next four decades and the latter due to the sheer size of the poverty challenge.

The business-as-usual evolution of the poverty numbers described above already takes into accounts the potential damages from climate change. As mentioned in the earlier sections, the adverse impacts of climate change are likely to be particularly damaging for agriculture, which is the primary source of income for the majority of today's poor. Today, the poverty headcount among those working in agriculture is nearly [twice] as high as for those who work in other sectors, and more than [60] percent of the poor rely on agriculture as their primary source of earnings. Thus, although assuming away damages from climate change lowers global poverty incidence by [0.16] percentage points, the poverty headcount in agriculture falls by [0.66] percentage points. In other words, damages from climate change increase the likelihood that the poor would be concentrated in agriculture (Figure 12). One of the reasons for this anti-poor bias of climate change is the adverse impact of global warming on the dispersion of agricultural incomes: the Gini coefficient of earnings in agriculture rises from [42.3] in a scenario with no climate damages to [43.2] when the damages are taken into account.

The global mitigation scenario in this paper does not have large impacts on the global income distribution and global poverty. Global inequality in 2050 is reduced from a Gini of [49.0] in the baseline scenario to a Gini of [48.7] when global emissions are capped. Although poverty increases slightly in most developing regions, global poverty actually declines (Table 1). This is an outcome of several opposing trends. On the one hand, the phase-in of emission taxes lowers per capita growth, which is a major avenue of escaping poverty. On the other hand, taxing emissions lowers the wage premiums paid to non-agriculture workers in a number of developing countries (particularly Latin American energy exporters) and also leads to lower relative food prices. These mechanisms combine to produce a slight overall pro-poor effect of mitigation policies.

Conclusions

To be completed…

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Annex A: Sector and regional aggregations

Table A-1: Sector aggregation[a]

No.	Abbre-viation	Definition
1	pdr	Paddy rice
2	wht	Wheat
3	gro	Other cereal grains
4	osd	Oil seeds
5	c_b	Sugar cane and beet
6	ocr	Other crops
		Vegetables and fruits (v_f), Plant-based fibers (pfb), Crops, n.e.s. (ocr)
7	lvs	Livestock
		Bovine cattle, sheep and goats, horses (ctl), Animal products n.e.s. (oap), Raw milk (rmk), Wool, silk-worm cocoons (wol)
8	frs	Forestry
9	coa	Coal
10	oil	Crude oil
11	gas	Natural gas
12	omn	Other mining
13	pfd	Processed food
		Fishing (fsh), Bovine cattle, sheep and goat, horse meat products (cmt), Meat products n.e.s. (omt), Vegetable oils and fats (vol), Dairy products (mil), Processed rice (pcr), Sugar (sgr), Food products n.e.s. (ofd), Beverages and tobacco products (b_t)
14	p_c	Refined oil
15	crp	Chemicals rubber and plastics
16	nrx	Energy intensive manufacturing
		Paper products, publishing (ppp), Mineral products n.e.s. (nmm), Ferrous metals (i_s), Metals n.e.s. (nfm)
17	mnu	Other manufacturing
		Textiles (tex), Wearing apparel (wap), Leather products (lea), Wood products (lum), Metal products (fmp), Motor vehicles and parts (mvh), Transport equipment n.e.s. (otn), Electronic equipment (ele), Machinery and equipment n.e.s. (ome), Manufactures n.e.s. (omf)
18	ely	Electricity
19	gdt	Gas distribution
20	cns	Construction
21	trp	Transport services
		Transport n.e.s. (otp), Sea transport (wtp), Air transport (atp)
22	osv	Other services
		Water (wtr), Trade (trd), Communication (cmn), Financial services n.e.s. (ofi), Insurance (isr), Business services n.e.s. (obs), Recreation and other services (ros), Public administration and defence, education, health services (osg), Dwellings (dwe)

Note: a. Each modeled sector is composed of one or more of the 57 sectors defined in the GTAP release 6.2 documentation. Modeled sectors that are composed of two or more GTAP sectors include the descriptions of the underlying sectors.

Table A-2: Regional aggregation[a]

No.	Abbre-viation	Definition
1	usa	United States
2	can	Canada
3	jpn	Japan
4	hyo	Rest of high income
		Australia (aus), New Zealand (nzl), Rest of Oceania (xoc), Hong Kong (hkg), Korea (kor), Taiwan (twn), Singapore (sgp)
5	eur	EU 27 and EFTA
		Rest of North America (xna), Austria (aut), Belgium (bel), Denmark (dnk), Finland (fin), France (fra), Germany (deu), United Kingdom (gbr), Greece (grc), Ireland (irl), Italy (ita), Luxembourg (lux), Netherlands (nld), Portugal (prt), Spain (esp), Sweden (swe), Switzerland (che), Rest of EFTA (xef), Rest of Europe (xer), Bulgaria (bgr), Cyprus (cyp), Czech Republic (cze), Hungary (hun), Malta (mlt), Poland (pol), Romania (rom), Slovakia (svk), Slovenia (svn), Estonia (est), Latvia (lva), Lithuania (ltu)
6	chn	China
7	imy	Indonesia and Malaysia
		Indonesia (idn), Malaysia (mys)
8	xea	Rest of developing East Asia
		Rest of East Asia (xea), Cambodia (khm), Philippines (phl), Thailand (tha), Viet Nam (vnm), Rest of Southeast Asia (xse)
9	ind	India
10	xsa	Rest of South Asia
		Bangladesh (bgd), Pakistan (pak), Sri Lanka (lka), Rest of South Asia (xsa)
11	rus	Russia
12	xec	Rest of Europe and Central Asia
		Albania (alb), Croatia (hrv), Rest of Former Soviet Union (xsu), Turkey (tur)
13	mnx	MENA Energy exporters
		Iran (irn), Rest of Middle East (xme), Rest of North Africa (xnf)
14	xmn	Rest of MENA
		Egypt (egy), Morocco (mar), Tunisia (tun)
15	sst	Sub Saharan Africa
		Botswana (bwa), South Africa (zaf), Rest of South African Customs Union (xsc), Malawi (mwi), Mauritius (mus), Mozambique (moz), Tanzania (tza), Zambia (zmb), Zimbabwe (zwe), Rest of Southern African Development Community (xsd), Madagascar (mdg), Nigeria (nga), Senegal (sen), Uganda (uga), Rest of Sub-Saharan Africa (xss)
16	bra	Brazil
17	lcx	Other LAC energy exporters
		Mexico (mex), Bolivia (bol), Ecuador (ecu), Venezuela (ven)
18	xlc	Rest of LAC

	Colombia (col), Peru (per), Argentina (arg), Chile (chl), Paraguay (pry), Uruguay (ury), Rest of South America (xsm), Central America (xca), Rest of Free Trade Area of Americas (xfa), Rest of the Caribbean (xcb)

Note: a. Each modeled region is composed of one or more of the 96 regions defined in the GTAP release 6.2 documentation. Modeled regions that are composed of two or more GTAP regions include the descriptions of the underlying regions.

Annex B: Description of the GIDD model

This Appendix details the methodology for generating a counter-factual within-country distribution of income in the GIDD. The objective of the exercise is to create a hypothetical income distribution capturing three major changes in the structure of the population and the economy: (a) change in the age and skill composition of the population, (b) change in the allocation of workers across sectors in the economy, and (c) change in returns to labor by skill and occupation. Our analysis uses country-specific data at the *micro* level (household surveys) to *simulate* the impact of the three adjustments. Although in reality these changes take place simultaneously, in our simplified framework they are accommodated in a sequential fashion. In the remainder of this Appendix we explain in some detail the steps of the microsimulation model.

B.1 Socio-Demographic and Educational Changes

The starting point of our microsimulation exercise is a set of changes in the demographic structure. The relative size of the different age groups is modified following the United Nations (2007) population projections. Additionally, the changes in the demographic structure have an impact on the average educational attainment in the population, i.e. a "pipeline" effect; therefore, educational endowments are modified accordingly. The microsimulation model accounts for these changes by adjusting (or re-calibrating) the household survey data by means of two alternative re-weighting procedures.

Begin with a matrix of *individual* sampling weights $W=[w_{mn}]$, where N is the number of observations in the sample and $\boldsymbol{m}$ is a vector of individual-level characteristics targeted by the microsimulation model. Since in the majority of surveys the household, rather than the individual, is the sampling unit, the individual weight is often, but not always, the household weight divided by the number of household members.[33] The sum of all weights in W gives us total population P:[34]

$$P = \sum_{m=1}^{M} \sum_{n=1}^{N} w_{m,n} = W\mathbf{i}_n\mathbf{i}_m^{'} \tag{B1}$$

where $\mathbf{i_n}$ and $\mathbf{i_m}$ are identity column vectors. The row sums define the totals of the relevant population sub-groups P_m:

$$P_m = \sum_{n=1}^{N} w_{m,n} = W\mathbf{i}_n \qquad \forall m = 1,\ldots,M \tag{B2}$$

In the current application of the GIDD, these population sub-groups are calculated as intersections of age and education projections, although the methodology can incorporate any number of additional partition rules: by gender, geographic area, ethnicity, etc. The demographic projections between 2000 and a future year are obtained from the United Nations (2007) in 5-year cohorts,

33 Certain surveys (e.g., Brazil and Venezuela) target certain individual-level characteristics (such as the gender composition of the sample) and therefore adjust the sampling weights at the individual level to be consistent with the census data.

34 In most cases, aggregate statistics like census data will differ from the sum of micro sources such as household surveys; a cross-entropy method to reconcile household survey and national accounts data is developed in Robilliard and Robinson (2003).

ranging from 0 to 100 years of age.[35] Educational projections are based on the forecasted demographic structure by exploiting the heterogeneity of educational attainments across age groups.

Assume that at time *t* young individuals are more educated than older ones. As the population ages, the old and unskilled of today will be replaced by the young and more skilled individuals. Therefore at time *t+1*, the overall skill endowments increase as a consequence of the change in the structure of the population—even in the absence of policies intended to increase educational attainments. In other words, this "pipeline" effect maintains a constant distribution of skills within age groups, but leads to gradually rising average educational attainments at the national level. For example, if at time *t* half of the population in the cohort formed by individuals whose age is between 25 and 30 have post-secondary education, then, after 10 year (Bt *t+1*), half of the population between 35 and 40 will have post-secondary education.

Combined with the exogenous population forecasts, these *semi-exogenous* projections of skill levels (Figure YY) yield the target (or expected) population in each sub-group *m* such that:

$$\hat{P}_m = \sum_{n=1}^{N} a_{m,n} w_{m,n} = (A.W)\mathbf{i}_n \qquad \forall m = 1,\ldots,M \qquad \text{(B3)}$$

where $A=[a_{mn}]$ is a matrix of multipliers which ensure that the *m* constraints on the future structure of the population $\hat{P}$ are satisfied and (B.*W*) is the hadamard product.[36] This system has (*m*x*n*)-1 variables but only *m* constraints and is therefore underdetermined. The two possible solutions are to add equations to make the system exactly identified, or to solve an optimization problem that minimizes the distance between the original matrix *W* and the final matrix (B.*W*). Both solutions are available in the GIDD.

The first approach imposes the restriction that the multipliers must be equal for each sub-group *m*:

$$a_{m,n} = \bar{a}_m \qquad \forall m = 1,\ldots,M \qquad \text{(B4)}$$

This approach reduces the problem to a system of *m* equations and *m* unknowns and thus yields an easy solution:

$$\bar{a}_m = \hat{P}_m \left(\sum_{n=1}^{N} w_{m,n} \right)^{-1} \qquad \forall m = 1,\ldots,M \qquad \text{(B5)}$$

Beyond its simplicity, there is one additional advantage of this method: it maintains the original distribution of personal characteristics within each of the *m* population sub-groups. In other words, the distribution of personal characteristics in $\hat{P}$ differs from the distribution in *P* only due to changes in the between-group variance. Therefore, within the *m* groups, the original survey design remains unaltered.

Despite these advantages, the above method can produce significantly flawed results if the sampling units are sufficiently dispersed across the *m* sub-groups. For example, if the variable of interest is

35 The assumptions behind these projections can be found in: http://esa.un.org/unpp/

36 Note that we are not imposing the total population constraint $\hat{P} = \sum_{m=1}^{M} \sum_{n=1}^{N} a_{m,n} w_{m,n} = (A.W)\mathbf{i}_n \mathbf{i}'_m$, which would make the system over-determined in *m* variables. The underlying assumption is that the sub-group targets $\hat{P}_m$ add up to the total population $\hat{P}$ (either originally or following normalization by the user), which makes one of the equations linearly dependent and allows us to drop it.

household per capita consumption and the *m* sub-groups span across age and skill endowments, relatively few households would fall entirely into one sub-group. For households spanning more than one sub-group, the re-weighting procedure will then assign higher sampling weights to some household members and lower weights to others. This is unsatisfactory for two reasons. First, the intention of any re-weighting procedure is to produce "clones" of observations in the initial dataset. However, the structure of an average household in $\hat{P}$ will differ from the structure of the average household in *P*. Second, the procedure can also have unintended consequences for the distribution of per capita consumption.

As an example, consider two households: one is composed of two "old" individuals, while the other contains one "old" and one "young" member. With an upward-sloping age-consumption profile, the per capita consumption of the first household would generally be above those of the second. As the population ages, the first household will become more representative of the overall demographic structure and the average consumption in the population will increase. However, in the procedure described by equation (B5), the increase in consumption due to higher weight of the first household will be somewhat offset by the rising contribution of the second household which has lower per capita consumption (because both the sampling weights are increased for both households). Therefore, the upward-sloping age-consumption profile observed in the cross-section may not be accurately reflected in the outcome of the re-weighting procedure. In order to address these shortcomings, the GIDD allows for a second alternative for estimating the *A* matrix.

The procedure works by minimizing a distance function $D(w_{mn},\ a_{mn}w_{mn}) = D(B_{mn})$ subject to a set of constraints in equation (B3). It is therefore similar to the methodology of Robilliard and Robinson (2003) and Cai, Creedy and Kelb (2006). However, it differs from the previous efforts in one crucial aspect by explicitly recognizing the importance of maintaining the household structure of the original survey while respecting the individual-level constraints of equation (B3). Consider minimizing a simple distance function of the following form:

$$\sum_n 0.5\left(\frac{\sum_{m=1}^{M} a_{m,n} w_{m,n}}{\sum_{m=1}^{M} w_{m,n}} - 1\right)^2 \qquad \text{(B6)}$$

subject to the constraints in equation (B3) and an additional set of constraints below:

$$r_{m,n} = \frac{w_{m,n}}{\sum_{m=1}^{M} w_{m,n}} = \frac{a_{m,n} w_{m,n}}{\sum_{m=1}^{M} a_{m,n} w_{m,n}} \qquad \text{(B7)}$$

The solution to this minimization problem is a matrix *A* that penalizes the squared percentage deviations of (B.*W*) from *W* while meeting the set of sub-group constraints $\hat{P}_m$ *and* keeping the original ratio of individual to household weights unchanged for each household in the sample (equation A7). Equation (B7) implies that:

$$a_{m,n} = \bar{a}_n \qquad \forall n = 1, \ldots, N \qquad \text{(B8)}$$

which allows for a convenient re-statement of the minimization problem by simplifying equation (B6) and combining equations (B3) and (B8):

$$\min \sum_n 0.5(\bar{a}_n - 1)^2 \quad \text{s.t.} \quad \hat{P}_m = \sum_{n=1}^{N} a_{m,n} w_{m,n} = \sum_{n=1}^{N} \bar{a}_n w_{m,n} \qquad \text{(B9)}$$

The first order conditions are:

$$\bar{a}_n = 1 + \sum_{m=1}^{M} \lambda_m w_{m,n} \tag{B10}$$

$$\hat{P}_m = \sum_{n=1}^{N} \bar{a}_n w_{m,n} \tag{B11}$$

These can be written in matrix form as follows:

$$\begin{bmatrix} I & -W' \\ W & 0 \end{bmatrix} \begin{bmatrix} A \\ \Lambda \end{bmatrix} = \begin{bmatrix} \mathbf{i}_n \\ \hat{P} \end{bmatrix} \tag{B12}$$

The solution is:

$$\begin{bmatrix} A \\ \Lambda \end{bmatrix} = \begin{bmatrix} 0 & W'(WW')^{-1} \\ -(WW')^{-1}W & (WW')^{-1} \end{bmatrix} \begin{bmatrix} \mathbf{i}_n \\ \hat{P} \end{bmatrix} \tag{B13}$$

which gives a simple expression for Λ:

$$\Lambda = (WW')^{-1}\left(\hat{P} - W\mathbf{i}_n\right) \tag{B14}$$

The matrix to invert is *m*x*m*, which considerably reduces the dimensionality of the problem. Once the values for Λ are known, the first order condition (B10) can be used to obtain a solution for the *A* matrix.

B.2 Labor Reallocation

Changes in the rate of exit of workers from the traditional agricultural sector into manufacturing and services may occur as an outcome of the baseline growth process or as a result of specific policy interventions that affect the wage gap between the two types of activities. Workers will choose to abandon the agricultural sector if this choice represents an increase in their expected earnings. Therefore, any change in the rate of re-allocation of labor across sectors will have an impact on income distribution. At the macro level, the CGE model will predict the number of workers moving out of the traditional agricultural sector into the relatively modern industrial and service sectors. At the micro level, the macro constraint of moving *N* workers out of agriculture and into manufacturing and service activities can be satisfied by a large number of potential combinations of workers. Some studies (e.g., Bussolo et al 2008) resolve this ambiguity by randomly picking migrants from the agricultural labor supply until the aggregate constraint is satisfied. The GIDD employs a more sophisticated methodology by estimating the conditional probability function of being a worker in the non-agricultural sector, ranking the workers in the agricultural sector according to their probability score, and assigning migrant status to workers with the highest score until *N* workers have been selected. Currently, this procedure is implemented at the household level—where the head of household makes the migration decision and takes the rest of the household members with her—although the methodology can also be applied at the individual level.[37]

The probability of observing that individual *j* works in the non-agricultural sector is modeled with a probit equation:

[37] The choice for implementing the migration routine at the household level is driven by data constraints. In a large number of GIDD surveys (particularly consumption-based surveys, which make up 54 of the 73 surveys in the GIDD) contributions of individual incomes to total household income cannot be identified, forcing us to operate at the household level.

$$\Pr(NA_j = 1) = P(X_j, Z_j) \quad \text{(B15)}$$

where X_j and Z_j are vectors of personal and household characteristics of individual *j*, respectively. Following estimation, workers in the agricultural sector are assigned a probability score based on their *X* and *Z* characteristics and the estimated vector of common determinants $\boldsymbol{\beta}_p$. The workers are then ordered based on this probability score, and workers with higher probabilities to be in non-agricultural sectors are moved out of the agricultural sector up to a point where the predicted share of workers by sector (the macro constraint) is satisfied.

Once the agricultural workers with a highest likelihood of being in non-agricultural sectors have changed sector of employment, the next step is to adjust their labor remuneration. The first step in this process is estimating a Mincer equation for workers in agricultural (B) and non-agricultural (*NA*) sectors:

$$\ln(Y)_{j,s} = \mathbf{X}_j \boldsymbol{\beta}_s + \varepsilon_{j,s} \qquad s = (A, NA) \quad \text{(B16)}$$

Migrants *carry* their personal endowments $\mathbf{X}_j$ and their residual ε_j from one sector to the other. Nevertheless once they *arrive* to the non-agricultural sectors, their vector of personal characteristics $\mathbf{X}_j$ will be rewarded with *prices* $\boldsymbol{\beta}_{NA}$ and their residuals will be re-scaled to take into account the differences in the distribution of unobservables between the agricultural and non-agricultural sectors. Hence assuming worker *j* is a migrant her income assignment function will be defined as:

$$\ln(Y)_{j,NA} = X_j \beta_{NA} + \varepsilon_j^* \quad \text{(B17)}$$

where $\varepsilon_j^* = \varepsilon_{j,A} * \dfrac{\sigma_{\varepsilon,NA}}{\sigma_{\varepsilon,A}}$ and $\sigma_{\varepsilon,s}$ is the standard deviation of the distribution of residuals in sector *s*.

B.3 Income Assignment

The final step in the GIDD microsimulation is to adjust factor returns by skill and sector, as well as the average income/consumption per capita, in accordance with the results of the CGE model. There are two potential difficulties in translating the price changes of the CGE model into the micro data. First, following the implementation of the re-weighting and migration routines certain changes have already taken place both in the average survey income and its distribution. Therefore, the macro constraints on changing returns to sector and skills [$y_{s,l}$] as well as the average income $\bar{y}$ are imposed *net* of the changes that have already taken place up to this stage. Second, achieving full consistency between macro and micro data is often difficult if not impossible.[38] Since there is no guarantee that the first period wages in the CGE model match the labor earnings in the micro data, directly passing the changes in factor returns from the former to the latter may result in inconsistent evolution of wage premiums in the two models. In extreme cases, wage gaps may even be reversed in one model but not in the other. In order to hedge against these potential complications while ensuring maximum consistency between the macro and micro outcomes, the GIDD adjusts the ratios between wage premiums rather than wages themselves.

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38 See the discussion in Bussolo et al 2008 for a more detailed statement of this consistency problem and some examples.

Beginning with a distribution of earnings by sector and skill [$y_{s,l}$] in the macro data, define a series of ($s+l$-1)wage gaps as follows:

$$g_{s,l} = \frac{y_{s,l}}{y_{1,1}} - 1 \qquad \text{(B18)}$$

where $y_{1,1}$ is the average labor earnings of unskilled workers in agriculture. The micro data will have a set of wage premiums $\left[g'_{s,l}\right]$ which may or may not be consistent with the macro data. The counterfactual wage gaps in the GIDD will then be calculated as:

$$\hat{g}'_{s,l} = g'_{s,l} \frac{\hat{g}_{s,l}}{g_{s,l}} \qquad \text{(B19)}$$

This implies that even if initial and final wages differ between the macro and micro models, the *percentage* change in the wage gaps (themselves expressed as percentage premiums over labor earnings of unskilled workers in agriculture) will be consistent across the two models. This eliminates the possibility of wage gap reversal and ensures that the distributional changes are consistently mapped from the macro to the micro data.

Note that equation (B19) does not change the average earnings of unskilled workers in agriculture and only operates on labor income. In order to adjust the micro data such that the percentage change in the per capita income/consumption y' matches the change in real consumption per capita y in the CGE model, a final adjustment is carried out:

$$\hat{y}' = y' \frac{\hat{y}}{y} \qquad \text{(B20)}$$

The adjustment of equation (B20) implicitly accounts for changes in land, natural resource, and capital prices because these enter the household budget constraint in the CGE model and thus have an income effect on consumption. Therefore, the income adjustment process described in equations (B18) and (B20) allows the changes in labor remuneration to affect the income distribution of a given country, but the change in welfare at the national level is determined by the changes in all factor prices, including land and capital.

This approach conveniently avoids the issue of identifying sources of household income different from labor, but is justifiable on several grounds. First, it avoids the difficulties involved in estimating the contribution of capital to household earnings.[39] Second, movements in skilled wage and returns to capital are often correlated, so the GIDD is able to capture the distributional impacts of changing returns to capital through equation (B19). Third, the empirical literature on decomposing changes in the income distribution over time (e.g., Ferreira et al 2004) is usually able to explain much of the change in total inequality without resorting to estimation of capital incomes.

[39] Most econometric solutions to the problem of imputing capital earnings ignore the selection bias in the self-employment decision. Furthermore, it is questionable whether it is possible even in principle to extract information on capital income from surveys that are generally not designed to capture this information and where definitions of "capital" may vary widely between micro data and national accounts.

Table B-1: Household Surveys in the GIDD

Region	Covered population	Actual population	Covered Population (%)
World	**5,498,162**	**6,076,509**	**90.48**
East Asia and Pacific	1,733,358	1,817,232	95.38
Eastern Europe and Central Asia	460,385	471,549	97.63
High Income Countries	764,285	974,612	78.42
Latin America	500,199	515,069	97.11
Middle East and North Africa	190,397	276,447	68.87
South Asia	1,332,800	1,358,294	98.12
Sub-Saharan Africa	516,737	663,305	77.90

Economy	Covered population	Actual population	Data used
East Asia and Pacific	**1,733,358**	**1,805,691**	
China	1,260,000	1,260,000	grouped
Indonesia	212,000	212,000	individual
Vietnam	80,400	80,400	individual
Philippines	71,600	71,600	individual
Thailand	61,700	61,700	individual
Malaysia	23,300	23,300	grouped
Cambodia	11,900	11,900	individual
Lao PDR	4,927	4,927	individual
Papua New Guinea	5,133	5,133	grouped
Mongolia	2,398	2,398	grouped
Myanmar		47,700	
Korea, Dem. Rep.		21,900	
Fiji		811	
Timor-Leste		784	
Solomon Islands		419	
Vanuatu		191	
Samoa		177	
Micronesia, Fed. Sts.		107	
Tonga		100	
Kiribati		91	
Marshall Islands		53	
Eastern Europe and Central Asia	**460,385**	**471,549**	
Russian Federation	136,000	146,000	individual
Turkey	69,600	67,400	individual
Ukraine	47,600	49,200	individual
Poland	38,300	38,500	individual
Uzbekistan	25,100	24,700	individual
Romania	21,800	22,400	individual
Kazakhstan	15,000	14,900	individual
Serbia and Montenegro	10,600	8,137	grouped
Czech Republic	10,300	10,300	grouped
Hungary	9,876	10,200	individual
Belarus	9,994	10,000	individual
Azerbaijan	8,199	8,049	individual
Bulgaria	7,906	8,060	individual
Tajikistan	6,376	6,159	individual

Slovak Republic	5,393	5,389	grouped
Georgia	4,514	4,720	individual
Kyrgyz Republic	5,008	4,915	individual
Turkmenistan	4,644	4,502	grouped
Croatia	4,446	4,503	grouped
Moldova	4,259	4,275	individual
Lithuania	3,477	3,500	individual
Armenia	3,065	3,082	individual
Albania	3,139	3,062	individual
Latvia	2,383	2,372	grouped
Estonia	1,363	1,370	individual
Macedonia, FYR	2,044	2,010	individual
Bosnia and Herzegovina		3,847	
High Income Countries	**764,285**	**974,612**	
United States	282,000	282,000	grouped
Germany	82,200	82,200	grouped
France	58,900	58,900	grouped
United Kingdom	58,800	59,700	grouped
Italy	57,700	56,900	grouped
Korea, Rep.	47,000	47,000	grouped
Spain	40,500	40,300	grouped
Canada	30,800	30,800	grouped
Netherlands	15,900	15,900	grouped
Greece	10,900	10,900	grouped
Belgium	10,300	10,300	grouped
Portugal	10,100	10,200	grouped
Sweden	8,875	8,869	grouped
Austria	8,011	8,012	grouped
Hong Kong, China	6,669	6,665	grouped
Israel	6,282	6,289	grouped
Denmark	5,338	5,337	grouped
Finland	5,177	5,176	grouped
Norway	4,492	4,491	grouped
Singapore	4,020	4,018	grouped
New Zealand	3,864	3,858	grouped
Ireland	3,815	3,805	grouped
Slovenia	1,986	1,989	grouped
Luxembourg	441	438	grouped
Netherlands Antilles	215	176	grouped
Japan		127,000	
Taiwan, China		22,200	
Saudi Arabia		20,700	
Australia		19,200	
Switzerland		7,184	
Puerto Rico		3,816	
United Arab Emirates		3,247	
Kuwait		2,190	
Cyprus		694	
Bahrain		672	
Qatar		606	
Macao, China		444	
Malta		390	
Brunei Darussalam		333	
Bahamas, The		301	

Iceland		281	
French Polynesia		236	
New Caledonia		213	
Guam		155	
Channel Islands		147	
Virgin Islands (U.S.)		109	
Antigua and Barbuda		76	
Isle of Man		76	
Bermuda		62	
Greenland		56	
Latin America	**500,199**	**515,069**	
Brazil	172,000	174,000	individual
Mexico	98,000	98,000	individual
Colombia	41,600	42,100	individual
Argentina	37,300	36,900	individual
Peru	26,800	26,000	individual
Venezuela, RB	24,300	24,300	individual
Chile	15,200	15,400	individual
Ecuador	12,000	12,300	individual
Guatemala	11,800	11,200	individual
Bolivia	8,514	8,317	individual
Dominican Republic	7,950	8,265	individual
Haiti	8,146	7,939	individual
Honduras	6,281	6,424	individual
El Salvador	6,409	6,280	individual
Paraguay	5,386	5,346	individual
Nicaragua	5,186	4,920	individual
Costa Rica	3,805	3,929	individual
Uruguay	3,332	3,342	individual
Panama	2,849	2,950	individual
Jamaica	2,607	2,589	individual
Guyana	733	744	individual
Cuba		11,100	
Trinidad and Tobago		1,285	
Suriname		434	
Barbados		266	
Belize		250	
St. Lucia		156	
St. Vincent and the Grenadines		116	
Grenada		101	
Dominica		71	
St. Kitts and Nevis		44	
Middle East and North Africa	**190,397**	**276,447**	
Egypt, Arab Rep.	67,300	67,300	grouped
Iran, Islamic Rep.	63,700	63,700	grouped
Morocco	27,800	27,800	individual
Yemen, Rep.	16,500	17,900	individual
Tunisia	9,565	9,564	grouped
Jordan	5,532	4,857	individual
Algeria		30,500	
Iraq		23,200	
Syrian Arab Republic		16,800	
Libya		5,306	
Lebanon		3,398	

West Bank and Gaza		2,966	
Oman		2,442	
Djibouti		715	
South Asia	**1,332,800**	**1,358,294**	
India	1,020,000	1,020,000	individual
Pakistan	142,000	138,000	individual
Bangladesh	131,000	129,000	individual
Nepal	20,800	24,400	individual
Sri Lanka	19,000	19,400	individual
Afghanistan		26,600	
Bhutan		604	
Maldives		290	
Sub-Saharan Africa	**516,737**	**663,305**	
Nigeria	137,000	118,000	individual
Ethiopia	64,300	64,300	individual
South Africa	43,900	44,000	individual
Tanzania	34,500	34,800	individual
Kenya	28,100	30,700	individual
Uganda	24,600	24,300	individual
Ghana	19,300	19,900	individual
Côte d'Ivoire	16,500	16,700	individual
Madagascar	16,000	16,200	individual
Cameroon	15,500	14,900	individual
Zimbabwe	12,600	12,600	grouped
Zambia	12,600	10,700	grouped
Niger	11,800	11,800	grouped
Mali	11,100	11,600	individual
Burkina Faso	10,800	11,300	individual
Malawi	10,300	11,500	grouped
Rwanda	8,024	8,025	grouped
Guinea	7,929	8,434	individual
Senegal	7,914	10,300	individual
Benin	6,718	7,197	individual
Burundi	6,563	6,486	individual
Sierra Leone	4,509	4,509	grouped
Mauritania	2,668	2,645	individual
Lesotho	1,743	1,788	grouped
Gambia, The	1,217	1,316	individual
Comoros	554	540	grouped
Congo, Dem. Rep.		50,100	
Sudan		32,900	
Mozambique		17,900	
Angola		13,800	
Chad		8,216	
Somalia		7,012	
Togo		5,364	
Central African Republic		3,777	
Eritrea		3,557	
Congo, Rep.		3,438	
Liberia		3,065	
Namibia		1,894	
Botswana		1,754	
Guinea-Bissau		1,366	
Gabon		1,272	

Mauritius	1,187
Swaziland	1,045
Cape Verde	451
Equatorial Guinea	449
São Tomé and Principe	140
Seychelles	81

Tables

Table 1: Poverty headcount, percent of population

	2000	BaU, 2050	BaUnd, 2050	GBL, 2050
East Asia and Pacific	47.07	0.59	0.53	0.60
Eastern Europe and Central Asia	10.92	1.09	1.09	1.09
Latin America and Caribbean	23.23	5.12	4.24	5.02
Middle East and North Africa	22.23	0.59	0.47	0.61
South Asia	81.64	0.01	0.01	0.01
Sub-Saharan Africa	75.25	2.96	2.85	2.98
Developing countries	49.00	1.46	1.30	1.46

Source: Authors' simulations with the GIDD and ENVISAGE models

Figures

Figure 1: Production structure nesting

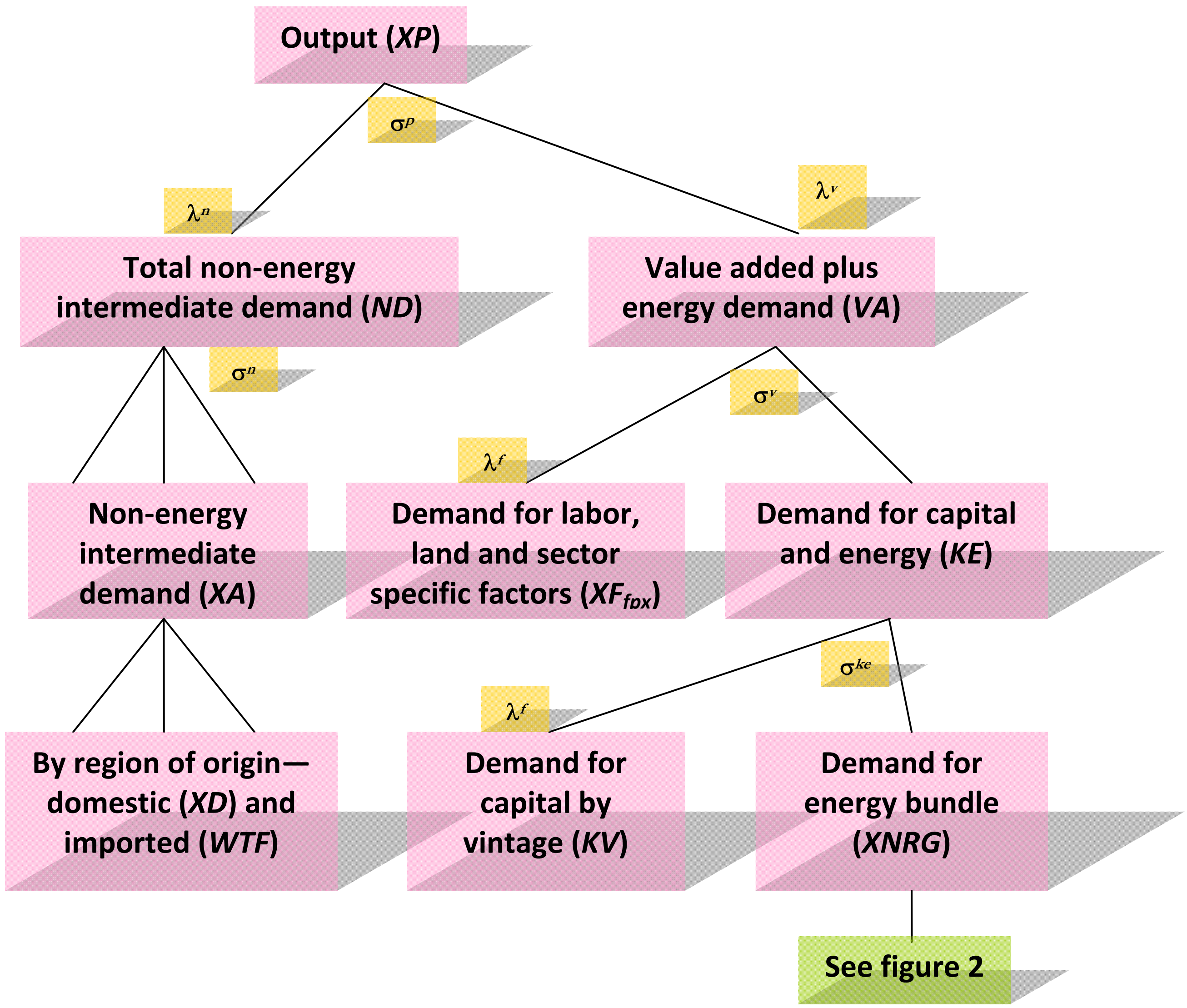


Figure 2: Energy nesting

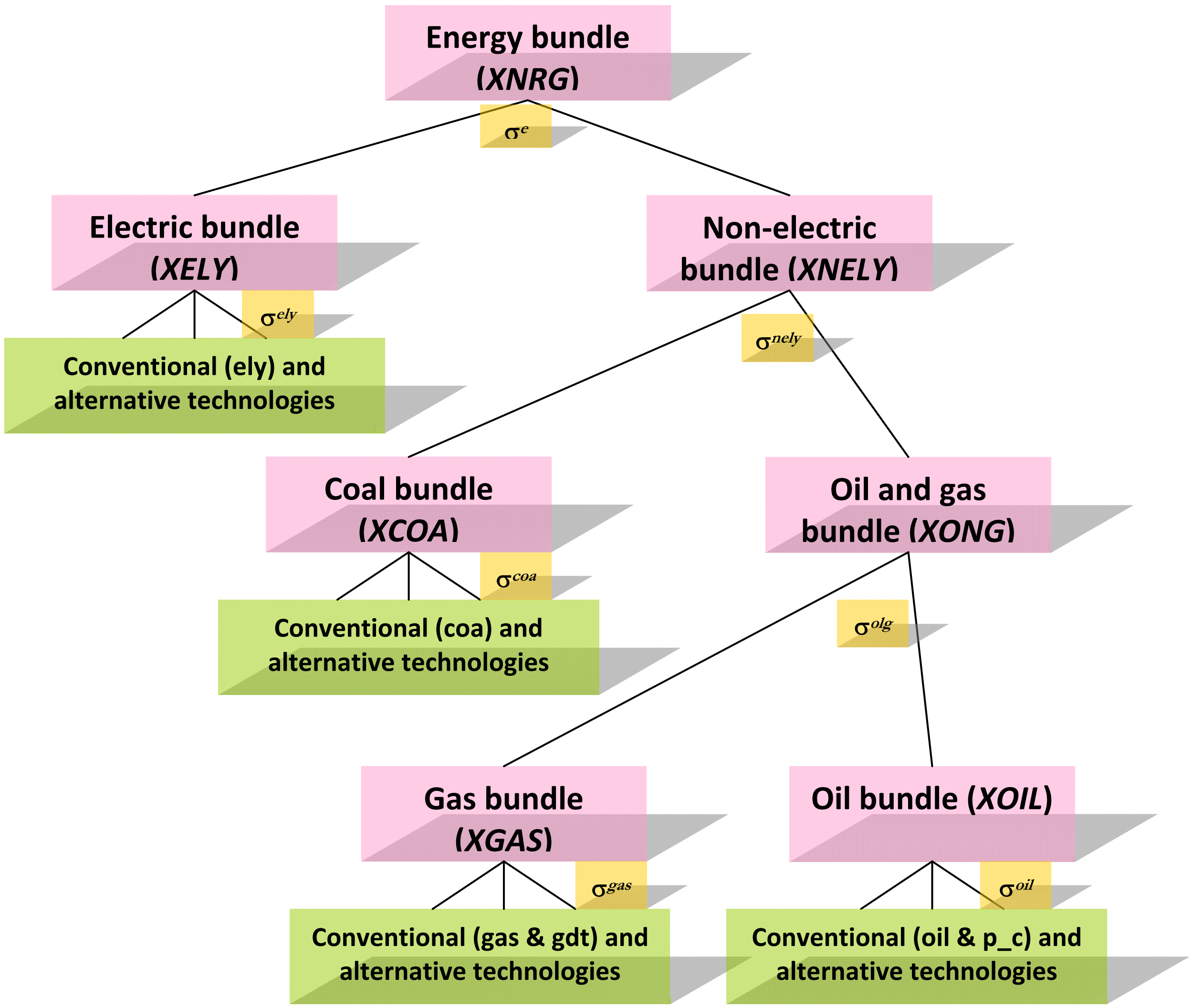


Figure 3: Domestic demand nesting

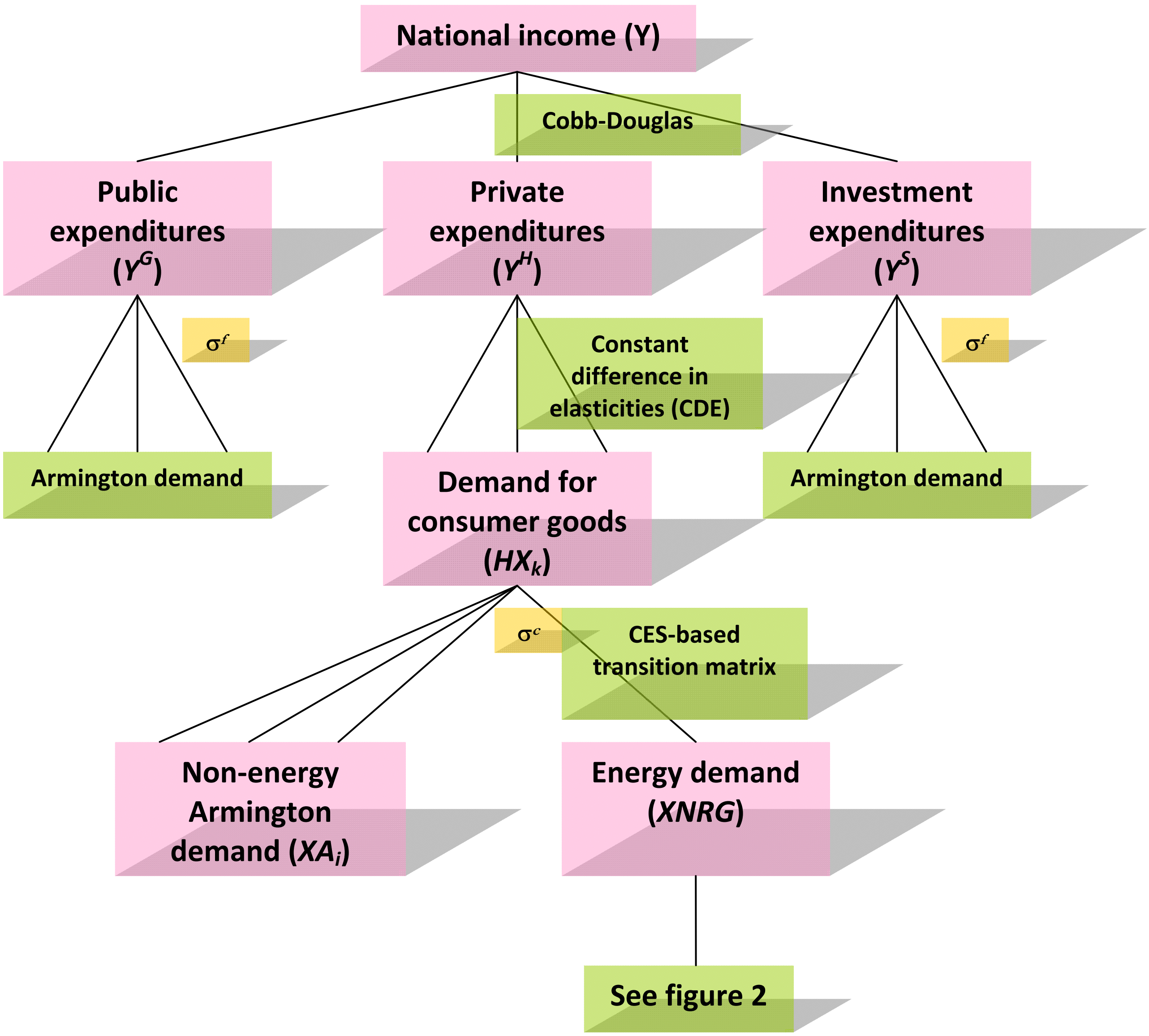


Figure 4: Output, supply and trade

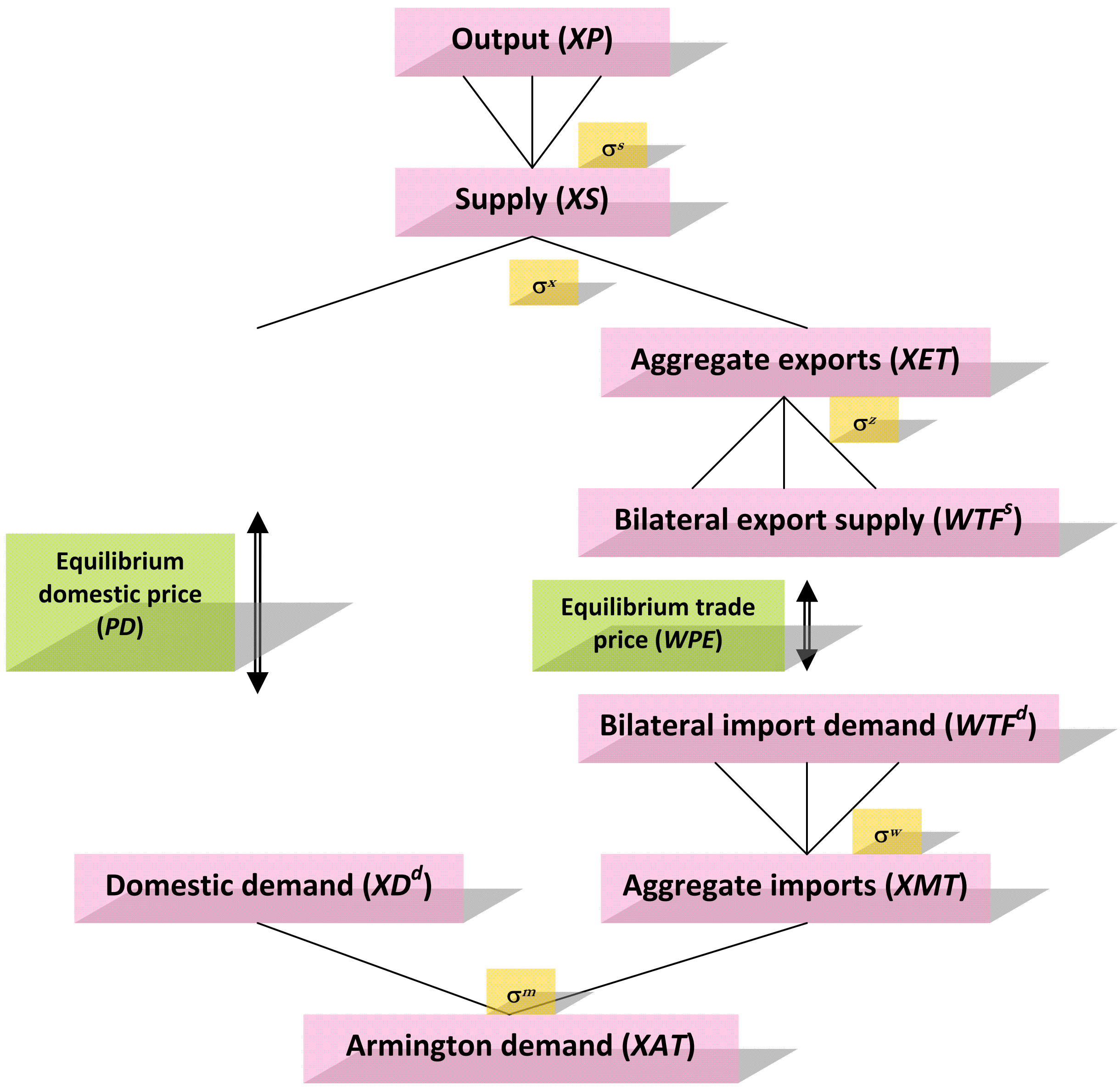


Figure 5 GIDD's conceptual framework

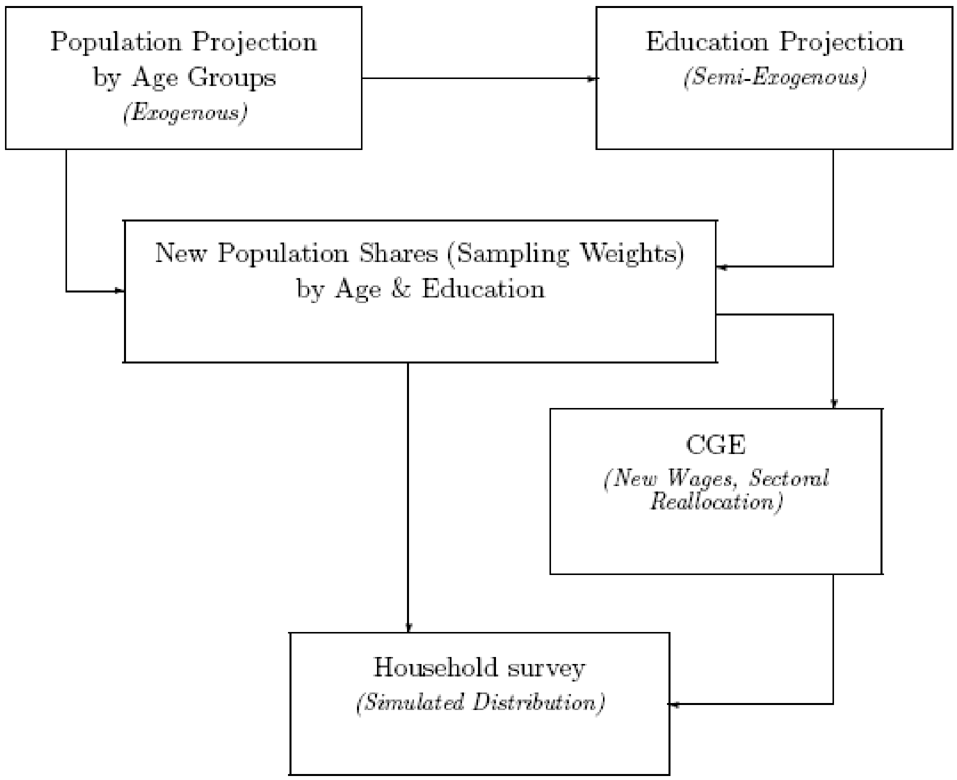
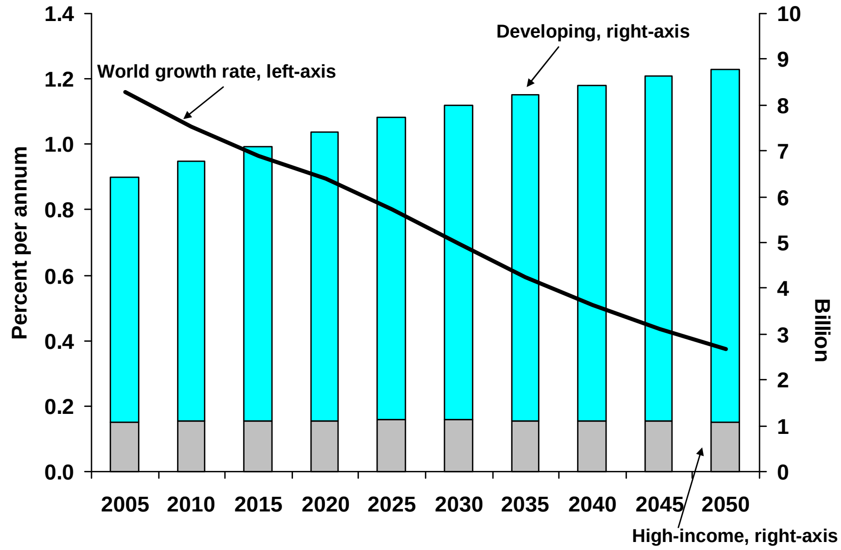
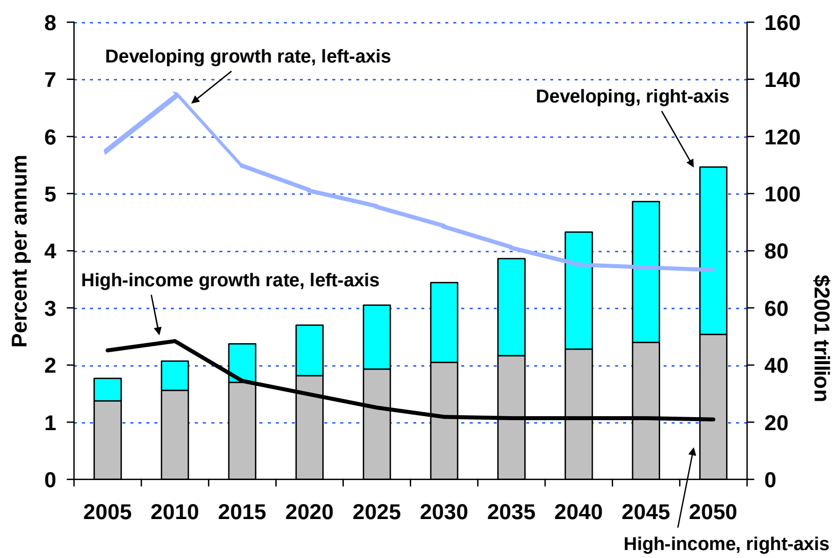


Figure 6: Population scenario



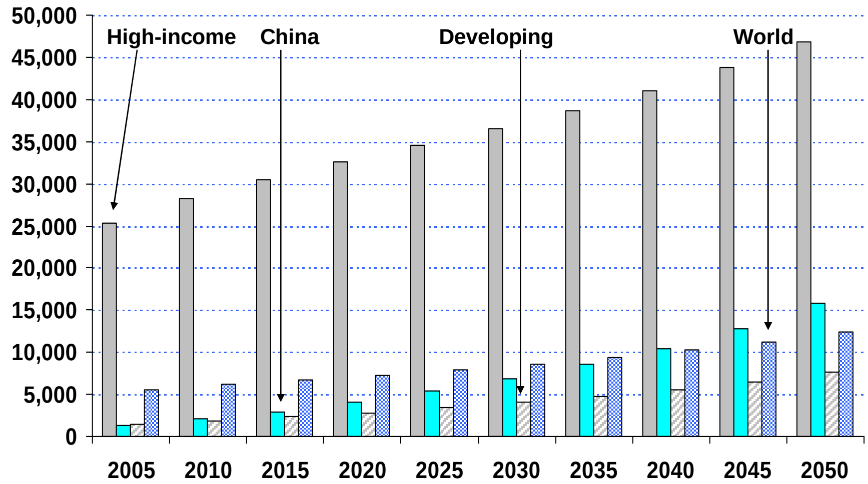
Source: UN Population Division and World Bank.

Figure 7: Economic growth scenario



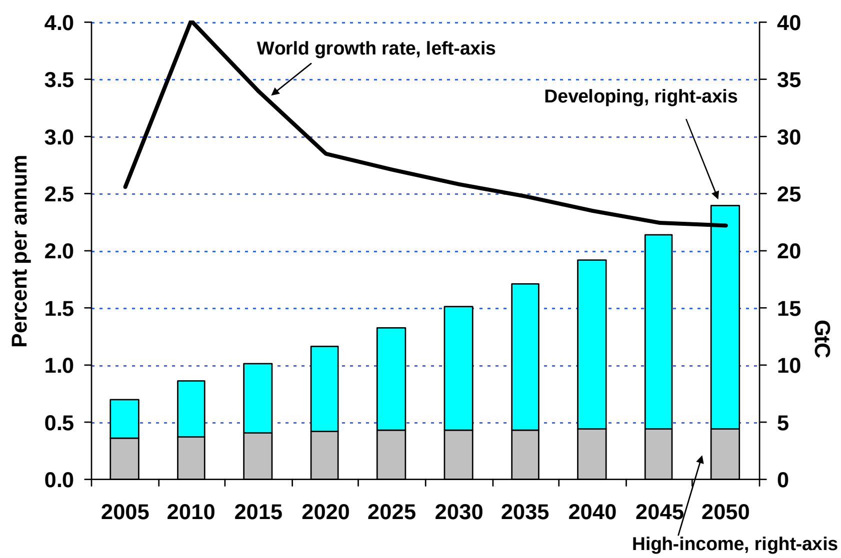
Source: Simulations with World Bank's ENVISAGE model.

Figure 8: Per capita incomes, $2001 MER



Note: Incomes measured at $2001 market exchange rates.
Source: Simulations with World Bank's ENVISAGE model.

Figure 9: Carbon emissions scenario from fossil fuels



Source: Simulations with World Bank's ENVISAGE model.

Figure 10: Baseline carbon emissions per capita

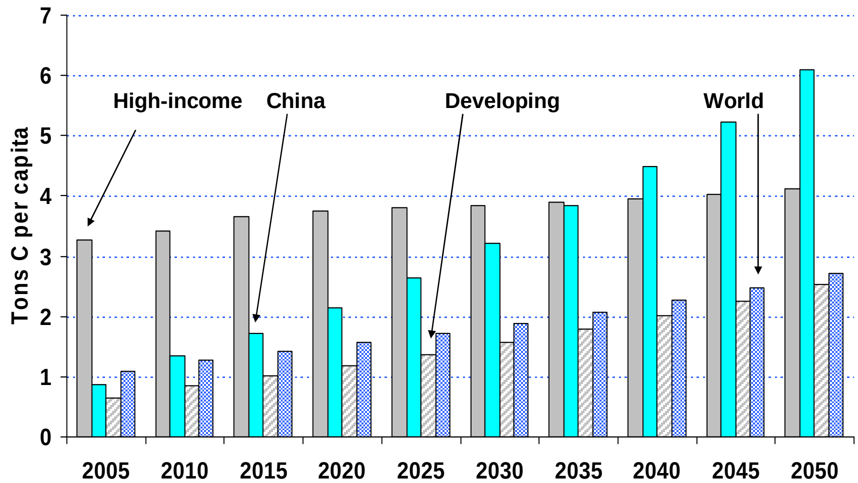
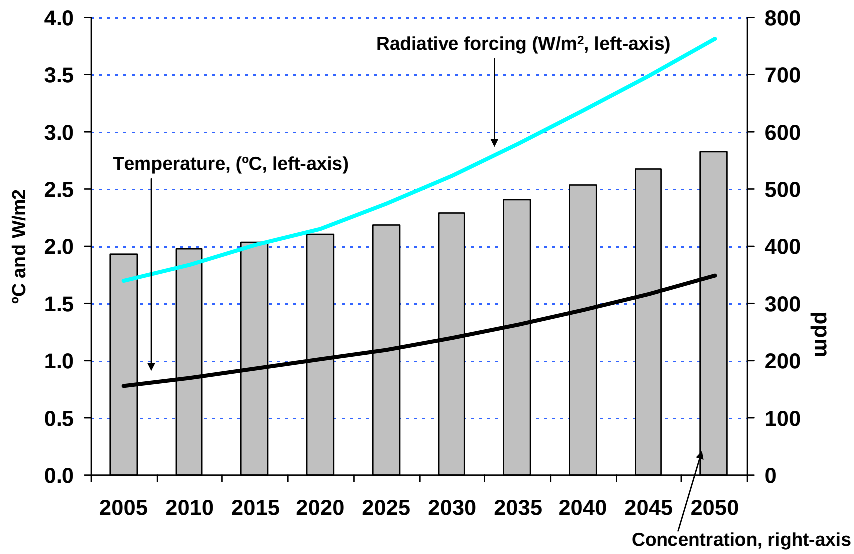
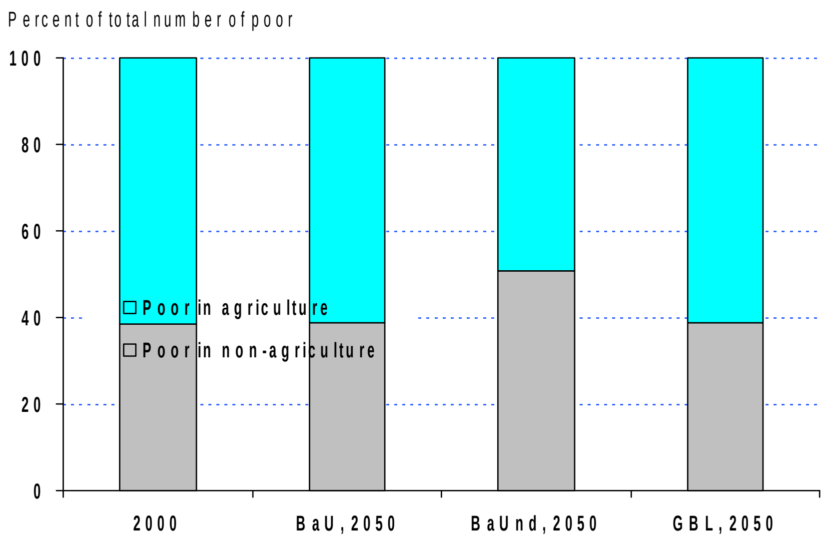


Figure 11: Baseline concentration and temperature



Note: Temperature is measured as changes in ºC since 1900.
Source: Simulations with World Bank's ENVISAGE model.

Figure 12: Climate change impacts on poverty



Note: BaU = baseline, BaUnd = baseline with no damages, GBL = global mitigation scenario.
Source: Simulations with World Bank's ENVISAGE model.