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# Globalized economy and national policies: Issues in comparing carbon emissions mitigation efforts under demographic and institutional asymmetry

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## Abstract

The success of the 2015 Paris Agreement in achieving its main temperature goal depends on its ability to increase the ambitions of individual countries to reduce their carbon emissions through effort comparison and peer pressure. Despite the empirical relevance of demographic changes in affecting factor prices, economic growth, and capital flows across countries, most comparisons of countries' carbon emissions reduction efforts are based on models that cannot capture demographic effects. Overlooking future demographic changes is problematic given the profound yet asymmetric demographic changes that countries are undergoing. This paper uses a two-country life-cycle model to show that comparing carbon emissions mitigation efforts can be misleading if countries' baseline emissions trajectories do not account for demographic dividends and spillovers from one country to another from unsynchronized demographic changes and asymmetric institutions. Through capital flows, differences in the timing, speed, and magnitude of demographic changes can reduce the emissions baseline in one country while increasing it in another country relative to the baseline with no spillovers – an effect which is amplified by differences in institutions such as pension and social security systems. Models that do not consider the effect of demographic changes and the institutions on the economy and emissions may underestimate one country's carbon emissions reduction effort while overestimating that of another. Consequently, neglecting demographic changes when comparing countries' carbon emissions mitigation efforts can undermine the successful implementation of the Paris Agreement.

**Keywords**

Global imbalances, Demographic transition, Carbon emissions, Lifecycle model, Energy dependent production function.

**JEL Classification**

E2, F32, F41, J11, J13, J14, O13, Q43, C6

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# Globalized economy and national policies: Issues in comparing carbon emissions mitigation efforts under demographic and institutional asymmetry[*]

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July 20, 2022

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# 1 Introduction

Since the establishment of a global policy framework to tackle climate change, economic models have become increasingly important in evaluating and successfully implementing climate change agreements. The Paris Agreement, the current global policy framework on climate change, was almost universally accepted[1] because it allowed countries to determine their own emissions mitigation targets (UNFCCC, 2015, Article 4). However, due to this flexibility, economic models are crucial to the Agreement's successful implementation for three key reasons. First, they are needed to project global emissions to assess whether we are on track to achieving the 2-degree Celsius target set out in the Paris Agreement. Second, economic models allow us to translate various emissions reduction pledges put forth by countries to make apples-to-apples emissions reduction comparisons. Third, economic models are necessary to translate those emissions reductions into economically comparable mitigation efforts.[2] Effort comparison is critical within the Paris Agreement because of the lack of externally imposed mitigation targets. Given the opportunity to free-ride due to the climate being a public good (Edenhofer et al., 2015), individual countries are eager to mitigate their emissions only if they believe they can reap the benefits in the form of reduced global climate change.

Past experiences show us the complexity and importance of setting realistic emissions mitigation targets. Ironically, since the establishment of the UN framework on climate change and the Kyoto Protocol (KP) in 1994, global emissions have grown faster (Raupach et al., 2007) despite many developed countries setting emissions reduction targets. The apparent failure of the KP was due to a combination of factors. First, large emitters such as the United States (US) didn't join the KP and therefore had no emissions restraints. Second, for some countries with emissions restraints in the KP, the targets turned out to be non-binding[3]. Third, developing countries had no emissions restraint under the KP. China, which had developing country status along with India, has experienced spectacular economic and carbon emissions growth since the start of the KP, surpassing the US as the largest emitter in the world in 2006 (NEAA, 2007; Gregg et al., 2008).[4] Though successful

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[1] As of March 2022, 192 countries and the European Union has ratified the Paris Agreement (https://treaties.un.org).

[2] Regarding the costs and efforts of mitigation, there are two distinct ideas. The first concept relates to a direct cost associated with switching from carbon-emitting sources to carbon-neutral sources. Total mitigation costs for this are dependent on the scale of economic activity (Stern et al., 2012), population and productivity growth (Gillingham et al., 2018), the structure of the economy, and how easy it is to switch between carbon-emitting and carbon-neutral sources (McKibbin et al., 2011). Furthermore, because replacing carbon-emitting sources requires new investments, countries' real interest rates also determine mitigation costs (Lambrecht et al., 2006). The second concept regarding the effort or cost of mitigation is broader. Independent of the actual investments made to replace fossil fuels, some countries benefit more than others due to countries' transitioning to carbon-free economies. For instance, McKibbin et al. (2011) demonstrates that the economic costs associated with climate change mitigation strategies for countries that export fossil fuels are mostly caused by international rather than local policy. As a result, it is thought that the change in economic production and consumption caused by mitigation policy is the most comprehensive indicator of mitigation effort (See McKibbin et al. (2011); Aldy et al. (2017)).

[3] For example, former Soviet block countries set their mitigation targets relative to their emissions in 1990, which turned out to be non-binding given the economic downturn they experienced after the collapse of the Soviet Union (Brizga et al., 2013).

[4] Importantly, studies find that over half of China's high household savings, which accompanied

in reducing emissions to some extent (Kuriyama & Abe, 2018), the failure of the KP in restraining global emissions shows the importance of universal, realistic and ambitious mitigation goals.

As an acknowledgment of the complexity of comparing countries' mitigation efforts, studies often propose the use of multiple distinct models to make a robust comparison of emissions projections and mitigation efforts[5]. However, so far, effort comparison studies have only used models which cannot capture demographic effects[6] from a changing age structure of a population following the change in a country's fertility and mortality patterns. Furthermore, Gillingham et al. (2018) argue that multiple model comparison may not be adequate to represent uncertainty around future emissions which can be smaller compared to the uncertainty in emissions caused by exogenous factors such as future population growth. However, the study by Gillingham et al. (2018) also neglected the uncertainty around global emissions that can result from uncertainty around differences in demographic outlooks across countries. In a life-cycle model, demographic differences can affect a country's economic growth and emissions through capital flows. This paper explores this aspect by applying a life-cycle model and demonstrating that the more asymmetric the demographic changes are across countries, the more spillovers[7] there will be. Different demographic outlooks, therefore, have implications for both global emissions[8] and the baseline emissions projections of individual countries, and hence for effort comparison as well.

This paper examines the effects of nine relative demographic scenarios (based on three demographic transition scenarios for each country) on the emissions trajectories of two large countries inhabited by households with life-cycle savings, to investigate the sensitivity of emissions baselines to alternative demographic scenarios. There are two main contributions of this paper, the first methodological and the second thematic. First, this paper incorporates an energy-dependent production function widely used within climate and energy modeling literature[9] into a two-country tractable life-cycle model that is solved in annual frequency that can capture demographic dividends. These model features allow us to study the implica-

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its high economic growth causing capital outflow, in the last two decades can be attributed to its changing demographics (Curtis, Lugauer, & Mark, 2015).

[5] Barron et al. (2018) and Aldy et al. (2017) have presented results from four different models evaluating mitigation efforts implied by the proposed climate change targets of China, The EU, the US, and India. Other studies such as Fragkos et al. (2018) also presented multiple modelling approaches.

[6] Demographic effect pertains to change in economic growth that comes from the changing age structure of the population (D. Bloom et al., 2003). In a country with a falling fertility rate, additional economic growth comes from higher workforce growth and higher savings following the reduction in total dependency rates. D. E. Bloom and Williamson (1998) found that almost one-third of the high economic growth experienced by East Asia between 1965 and 1990 was due to demographic changes.

[7] Here, spillovers refer to changes in a country's economic growth in the short to medium term due to capital flows from another country, resulting in differences in a country's long-run output level.

[8] Cross-country capital flows can change the growth of countries. As long as different countries' energy and carbon intensity are not the same, the international flows of capital will change global emissions relative to if there were no capital flows. Empirical evidence on the convergence of energy and carbon intensity of the economies is limited (Emir et al., 2019).

[9] See Van der Werf (2008)'s study for empirical validity of production functions used within the energy-economy models for climate policy.

tions of demographic transition on economic growth and emissions both in the short and the long run while allowing cross-country spillovers. Second, to my knowledge, this is the first study that applies a life-cycle framework to study carbon emissions mitigation efforts under demographic changes. This paper aims to highlight the inter-linkages of countries' emissions trajectories through capital flows under asymmetric demographics and institutions.

Previous studies have demonstrated the sensitivity of emissions baselines to demographic changes. For example, using a two-period Overlapping generations (OLG) model with logarithmic utility and an Infinitely lived representative agent (ILA) model, Gerlagh et al. (2017) has shown how the two models can generate very different outcomes when used for projections under a demographic transition. One caveat of this study is that the two-period OLG models impose demographic structures that are extreme and not suitable for analyzing the effect of demographic changes (Gertler, 1999; Ferrero, 2010). Furthermore, logarithmic utility assumes the elasticity of intertemporal substitution to be 1, which nullifies the effect of interest rates on consumption and savings. Other studies by Dalton et al. (2008) and Neill et al. (2010) have looked at the emissions implications of population aging in the US and the world (represented by six regions) using a model with overlapping dynasties of households. They find that demographic transitions will impact a country's economic growth and emissions. However, dynastic models lack life-cycle savings (Niemeläinen, 2017) and therefore underestimate the change in aggregate savings during demographic transitions, which is the main feature that explains persistent capital flows across countries in the last three decades (Gourinchas & Rey, 2014; Bernanke, 2015). Another study by Garau et al. (2013) has used a large-scale numerical OLG model to study the impact of population aging in Italy on economic growth and emissions. By confining his focus only to Italy, however, Garau et al. (2013) misses the effect of demographic transitions in other large countries on Italy[10].

The analysis in this paper demonstrates that demographic changes can bring about substantial demographic dividends. This, in turn, can change a country's emission path, complicating our ability to compare countries' mitigation efforts if we use models that cannot capture demographic effects. In addition, unlike ILA models[11] which tend to interpret persistent trade imbalances as difference in subjective time preference rates across countries,[12] capital flows can also depend on demographic and institutional differences within life-cycle models.[13] Diverging demographics and asymmetric institutions across countries can, therefore, cause larger cross-border capital flows. In other words, demographic and institutional differences can result in spillovers, making emissions higher in one country and lower in the other relative to the absence of the capital flow — thereby further complicating effort comparison. Because demographic effects are time-varying, they are difficult to account for in models without demographics through exogenous parameters unless one can explicitly forecast the impact of the demographic changes on the relevant

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[10] Study by Grafenhofer et al. (2006) provides useful comparison of different OLG models

[11] In the climate economics literature, the ILA framework is the one that is most frequently used to simulate households' intertemporal decisions.

[12] For example, a study by Leimbach and Bauer (2021) have assumed different time preference rates for countries to match cross country current account imbalances.

[13] Liu (2021) provides a comprehensive review of empirical and theoretical literature on demographic change's impact on cross country capital flows within life-cycle models.

parameters.[14]

This paper consists of 5 sections. Section 2 summarizes key features of the model used to answer the research question. Section 3 provides analytical results while section 4 offers a quantitative investigation to supplement analytical results. Finally, section 5 provides the main conclusions of the paper together with a discussion of policy implications and potential future research.

# 2 Model

This section describes the main features of the model that is used for the quantitative analysis in section 4. The household side of the model is based on a two-country life-cycle model developed in Batsuuri (2022), which has four types of individuals who are at different life stages. Population dynamics, which is used for aggregation, is exogenous in the model, which dictates how many people are at each life stage in each period. For the production structure, this paper uses an energy-dependent production function that is widely used within applied climate economics literature[9] which is also used in Batsuuri (2020). Only a brief explanation on the key equations describing the model is provided in this paper. Please refer to (Batsuuri, 2022) for the household equations, and (Batsuuri, 2020) for the production side for a detailed description of the model. The equations describing the two countries are identical, and therefore, only equations for one country are described here. When necessary, upper index f refers to variables for the other country.

## 2.1 Population dynamics

As in Batsuuri (2022), population dynamics are exogenous in the model, with individuals going through four life stages being children, young workers, mature workers, and being a retiree. A set of probabilities that govern the transition from one life stage to another, as illustrated in Figure 1, generates population dynamics in the model. These probabilities are independent of the age of an individual to facilitate aggregation.

## 2.2 Households

There are four types of individuals in the economy: retirees, mature workers, young workers, and dependent children. The model assumes that the children are born to young workers, who are between 20-39 years old, who bear the time cost of raising children. In contrast, all workers, young and old, equally pay the children's consumption cost based on their respective labour productivity.

All types of individuals, except children, maximize their respective lifetime utility shown in equation 1 subject to own intertemporal budget constraints. The utility of an individual is represented by the non-expected utility function proposed by Farmer (1990), which provide certainty-equivalent decision rule in the face of income risk that arises due to stochastic transition probability from one life stage to

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[14] Liu et al. (2020) provides an analysis of the economic and environmental implications of the Paris agreement using a dynamic general equilibrium model of the global economy (G-cubed) that is well suited to take into account international capital flows. It could be possible to consider international capital flows due to future demographic differences in the G-cubed through calibration.

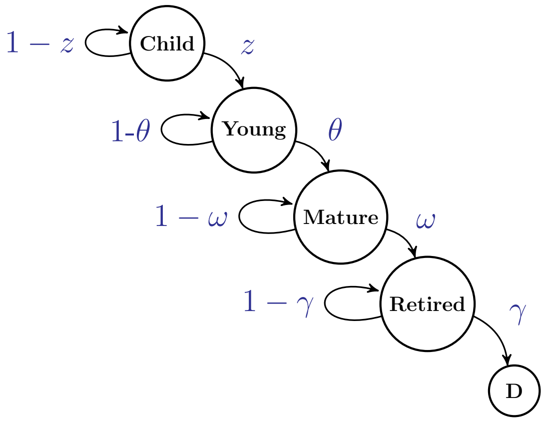

Figure 1: Transition probabilities from one life-stage to another

another. Different types of individuals differ by their respective intertemporal budget constraints. The superscript 'i' denotes the individual type: 'r' for retirees, 'm' for mature workers, 'y' for young workers, and 'c' for children.

$$V_t^i = \Big[(C_t^i)^\rho + \beta_i E(V_{t+1}|i)^\rho\Big]^{\frac{1}{\rho}} \tag{1}$$

where

$$\beta_i = \begin{cases} (1-\gamma_{t,t+1})\beta & \text{if i = r} \\ \beta & \text{if i = m,y} \end{cases}$$

$$E(V_{t+1}|i) = \begin{cases} V_{t+1}^r & \text{if i = r} \\ (1-\omega)V_{t+1}^m + \omega V_{t+1}^r & \text{if i = m} \\ (1-\theta)V_{t+1}^y + \theta V_{t+1}^m & \text{if i = y} \end{cases}$$

The solution to the individual problems gives decision rules that govern how the marginal propensity to consume (MPC) out of wealth evolves in response to interest rate and life expectancy. The equations for the MPCs are the same for individuals at same life stages and differs across individuals at different life stages, which is the main feature that gives rise to life-cycle consumption and savings in the model. Aggregate consumption function is given by equation 2:

$$C_t = \pi_t\Big[A_t R_t\Big(1+(\epsilon_t-1)\lambda_t^1+(\epsilon_{2,t}-1)\lambda_t^2\Big)+\epsilon_{2,t}(H_t^y+S_t^y)+\epsilon_t S_t^r+H_t^m+S_t^m\Big]+t^c W_t N_t^c \tag{2}$$

where $\lambda_t = A_t^r/A_t$ is the fraction of total assets in the economy held by retirees, $\lambda_{2,t} = A_t^y/A_t$ is the fraction of total assets in the economy held by young workers. The notations $\pi$, $\epsilon$, and $\epsilon_2$ represent MPCs of individuals at different life-stages which is influenced by life-expectancy and the interest rate.[15] Aggregate consumption is affected by demographic changes through changes in life expectancy and the changes in the size of people who have different life expectancies and different MPCs. This is the key feature that differentiates the model from perpetual youth model proposed

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[15] The proof on the relationship between the MPCs, the interest rate and the life expectancy is provided in the appendix section of Batsuuri (2022).

by Blanchard (1985) where individuals have same MPCs regardless of their age.[16] More detailed description of the population dynamics and the household problem can be found in Batsuuri (2022).

## 2.3 Firms

It is assumed that there is a representative firm producing final output combining energy and capital-labor composite while energy is produced combining clean and dirty energy inputs. In turn, clean and dirty energy inputs are produced combining capital, labor and resource specific factors ($X_{t.o}$ and $X_{t,s}$) that reflect technology and finite resources. The production structure of the economy is depicted in figure 2.

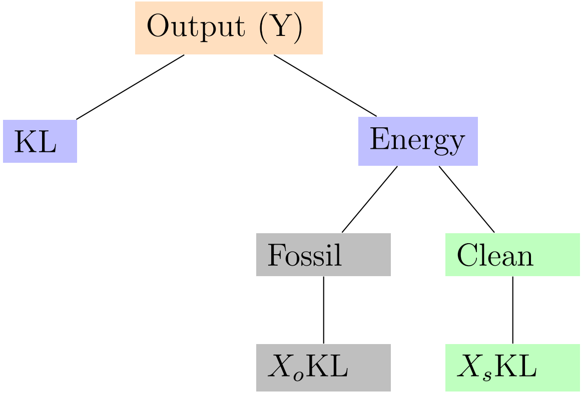

Figure 2: Production structure

The technology of the firm producing final output is represented by the function in equation 3.[17]

$$Y_t = \Big(\upsilon_1((X_{t,L}N_{t,y})^\alpha K_{t,y}^{1-\alpha})^\Psi + (1-\upsilon_1)(X_{t,e}E_t)^\Psi\Big)^{\frac{1}{\Psi}} \tag{3}$$

with labor augmenting technology growing at an exogenous rate of $x_l$.

$$X_{t+1,L} = (1+x_l)X_{t,L} \tag{4}$$

Energy augmenting technology ($X_{t,e}$) is assumed to be constant along the balanced growth path, but can change due to a deterministic technology shock.

Energy is produced combining clean and dirty energy inputs with technology represented by:

$$E_t = ((1-\eta_1)S_t^\Phi + \eta_1 O_t^\Phi)^{\frac{1}{\Phi}} \tag{5}$$

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[16] Blanchard (1985) and Weil (1989) proposed a tractable overlapping generations model that is easy to solve and widely used for policy analysis. However, it lacks a life-cycle structure by assuming that each individual has the same life expectancy hence MPCs.

[17] $\Psi$ is related to elasticity of substitution between Capital-Labor composite and Energy input via $\sigma_{KL,E} = \frac{1}{1-\Psi}$. $\Psi \in (-\infty, 0) \cup (0, 1]$. CES function includes 3 special cases under different $\Psi$ values. When $\Psi$ approaches -$\infty$, $\sigma_{KL,E}$ becomes 0 and the production function becomes a Leontief production function with perfect complementarity of inputs, when $\Psi$ approaches 1, $\sigma_{KL,E}$ approaches $\infty$ and inputs become perfect substitute in production. Lastly, when $\Psi$ approaches 0, $\sigma_{KL,E}$ becomes 1 and the production function becomes Cobb-Douglas production function.

where $O_t$ and $S_t$ represent dirty and clean energy inputs respectively while $\eta_1$ is the share of dirty energy inputs in the total energy production. Solution to final output and energy firms' problem provides quantity of final goods and energy production for given factor prices. Batsuuri (2020) provides more detailed description of firms' problem and their solution.

## 2.4 Characterization of equilibrium in the world economy

The competitive world equilibrium is defined as a sequence of endogenous quantity and price variables given the sequence of exogenous predetermined variables, and the initial values of all the predetermined variables such that in each country i) households maximize their utility subject to their budget constraints, ii) firms maximize their profits subject to their technology constraints, and iii) all markets clear.

Total assets in the home country is equal to total capital stock in the home country, government debt and net foreign asset holdings of the home country.

$$A_t = K_t + B_t + F_t \tag{6}$$

Foreign assets evolve according to

$$F_{t+1} = R_t F_t + NX_t \tag{7}$$

which links the goods and asset markets. Trade deficits and surpluses change net foreign asset holdings. The aggregate capital stock in the economy is equal to sum of the capital stocks in the final output, dirty and clean energy sectors.

$$K_t = K_{t,y} + K_{t,o} + K_{t,s} \tag{8}$$

The aggregate capital stock evolves according to

$$K_{t+1} = (1-\delta)K_t + I_t \tag{9}$$

The trade balance is determined by the difference between aggregate output and aggregate expenditures which include both private and government consumption and investment expenditure.

$$NX_t = Y_t - (C_t + I_t + G_t) \tag{10}$$

Free flow of assets between economies ensures equalization of gross interest rate $R_t$ between countries. In equilibrium, net asset holdings of the two countries cancel each other out.

$$F_t + F_t^f = 0 \tag{11}$$

Current account is the trade balance plus net interest payment on foreign assets.

$$CA_t = NX_t + (R_t - 1)F_t \tag{12}$$

Total labor force in the economy is equal to the number of mature workers plus labor supply by the young workers multiplied by their labor productivity. Labor market equilibrium is when total supply of labor equal to total demand for labor.

$$N_t = (\xi(1 - \frac{\lambda^c}{\psi_t^c}) + \psi_t^1)N_t^y \tag{13}$$

All quantity variables are normalized by population and productivity growth to estimate the steady-state of the model. The solution of the steady-state and the transition dynamics are solved using a non-linear Newton method. To close the model, government debt is assumed exogenous as fixed share of GDP. Detailed explanation of the algorithm used to solve the model can be found in Batsuuri (2022) and Julliard (2005).

# 3 Analysis

This section discusses how fertility and longevity transitions affect the economy. The impact of a fertility shock can be decomposed into its impact on labour force growth and aggregate savings and capital per effective labour, influencing output growth. In contrast, an increase in life expectancy at old age is assumed not to affect the growth of the labor force in effective units. Therefore, the impact of change in life expectancy at old age comes only through changes in aggregate savings and capital per effective labour. Specifically, for each transition, we can differentiate the main mechanisms of effect on capital per effective labour as direct through individual decision rules and indirect due to aggregation and general equilibrium effect.

## 3.1 Fertility shock

### 3.1.1 Growth of the effective labor force

Fertility shocks change the population dynamics, with the shock slowly propagating through different age cohorts' growth in sequence. More specifically, a fertility shock first changes the child dependency ratio and then the workforce's age structure before eventually changing the old-age dependency ratio. These ratios are important in determining labour supply, aggregate child consumption, income tax to finance child consumption, distribution of assets between different age cohorts and tax for social security which is modelled as pay-as-you-go pension. These effects will work to change aggregate savings and capital per effective labour. In addition, fertility shocks change the growth of effective labour force which is given by

$$n^{wf_\xi}_{t-1,t} = \frac{(\xi_t(1-\frac{\lambda^c_t}{\psi^c_t}) + \psi^1_t)n^y_{t-1,t}}{\xi_{t-1}(1-\frac{\lambda^c_{t-1}}{\psi^c_{t-1}}) + \psi^1_{t-1}} \tag{14}$$

Where $\psi^1_t$ is the mature to young worker ratio, $\psi^c_t$ is the children to young worker ratio, $\lambda^c_t$ is the time cost of children, $\xi$ is the productivity of young workers relative to mature workers. Linearizing equation (14) around its steady state provides following linear equation:

$$\hat{n}^{wf\xi}_t = \hat{n}^y_t + z_2(\hat{\psi}^1_t - \hat{\psi}^1_{t-1}) + z_3(\hat{\psi}^c_t - \hat{\psi}^c_{t-1}) \tag{15}$$

where $z_2$ and $z_3$ are positive constants that characterize the contribution and the effect of age structure of the workforce and the fertility rate on the effective labor supply at the steady state. The variables with hats denote deviation of a variable from its steady state in percentages. Specifically, $\hat{x}_t = Log(\frac{x_t}{x_{ss}})$. Given that both $z_2$ and $z_3$ are positive constants, it is clear from the above equation that the change in effective labour force depends on the change in young workers' growth and the change in the workforce's age structure and the change in fertility rate. In an economy where fertility is declining, both $(\hat{\psi}_t^1 - \hat{\psi}_{t-1}^1)$ and $(\hat{\psi}_t^c - \hat{\psi}_{t-1}^c)$ will be positive. Therefore, changes in the workforce's age structure and increased labour force participation due to a reduction in fertility rate will offset the negative impact on the growth of the fewer young workers entering the workforce following a fertility reduction.

### 3.1.2 Capital per effective labor

Even though fertility shocks do not directly affect individual decision rules, they can indirectly affect them by changing expected prices and the capitalized value of human and social security wealth. Fertility shocks change population dynamics. By changing the population's relative size at different life stages, fertility shocks will alter aggregate consumption and the distribution of assets among workers and retirees with different savings rates. Also, a reduction in the child dependency ratio immediately reduces the tax rate on labour income for child consumption, assumed as fixed per child in this model. However, because the workers have a higher discounting of the future due to finite work and lifetimes, reducing the tax for child consumption will increase workers' consumption less than the aggregate child consumption decrease.

In the short run, the reduction in fertility rate increases the aggregate savings. However, it is ambiguous how the capital per effective labour changes in the short run since the effective labour force also grows. Increase in savings will positively affect the capital per effective labour, while the workforce's growth will negatively affect it. In the long run, it is also ambiguous how the reduction in fertility rate affects the capital per effective labour. The decrease in fertility rate increases the old-age dependency ratio. Because retirees have lower savings rates, it will put negative pressure on aggregate savings. However, in the long run, the reduced fertility rate also reduces the growth of the population entering the workforce. Similar to its short-run effect, the effect of fertility reduction on the capital per effective labor will depend on the interaction between change in aggregate savings and the change in the growth of the effective labor force. With its non-linear and often conflicting effect both at the individual and aggregate level, it is impossible to analytically derive the impact of the fertility shock on capital per effective labour in this model. Therefore, a quantitative investigation is undertaken in the next section to investigate the effect of fertility reduction on capital and output per effective labour.

## 3.2 Longevity shock

The shock to life expectancy beyond working age doesn't affect the workforce's growth[18], age structure, and children to labor force ratio. Therefore, its effect mainly centers on aggregate savings and capital per effective labour through the individual savings decision and the retirees to worker ratio.

### 3.2.1 Capital per effective labor

In contrast to a fertility shock, a longevity shock, or transition will directly affect individual decision rules. Everyone, who make their consumption and savings deci-

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[18] To simplify the analysis, retirement age is assumed as fixed. It is possible to simulate change in retirement age.

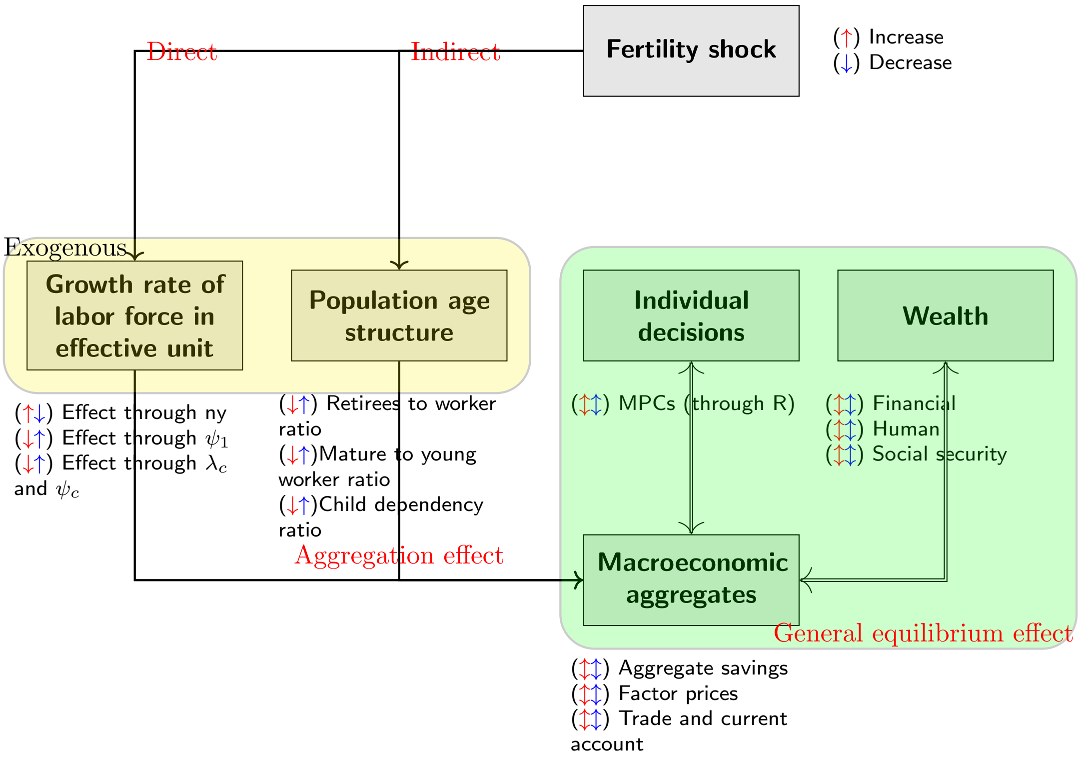

Figure 3: Effect of fertility shock

sion based on their expected lifetime, reduces their marginal propensity to consume when life expectancy after retirement increases. Only consumption by the children is not affected because they consume what they are given and do not decide.[19] An increase in life expectancy reduces retirees' MPC the largest when the shock hits. In addition to its direct impact on the individual's MPCs, longevity changes can indirectly impact the MPCs and the individual consumption by changing factor prices and wealth through aggregation. The reduction in interest rate will reduce retirees' consumption by further decreasing the MPCs, under the selected value used for the elasticity of intertemporal substitution (EIS) and reducing the financial wealth of the retirees who are net lenders. On the other hand, a reduction in the interest rate will increase the capitalized value of workers' human wealth by increasing wage and reducing the discount rate or the cost of borrowing against future income. Therefore, the effect of the longevity changes on workers' consumption is ambiguous.

Moreover, the aggregation effect is further complicated by the effect of a longevity transition on aggregate savings and capital per effective labour. The increase in life expectancy at old age increases retirees to worker ratio, increasing aggregate assets held by retirees who have a higher marginal propensity to consume. Again, with the rich demographic details and the effect of the longevity shock working through individual, general equilibrium, and aggregation, it is ambiguous how the longevity transition affects savings and capital per effective labour. Therefore, the analysis is supplemented by a quantitative investigation in the next section.

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[19] This paper abstracts from endogenous fertility and bequest. With endogenous fertility and bequest, transfer to children could change as well. For example, Day (2016) presents a model with endogenous fertility and transfer to children. The model shows a non-linear relationship between wage rate, fertility rate and investment in children.

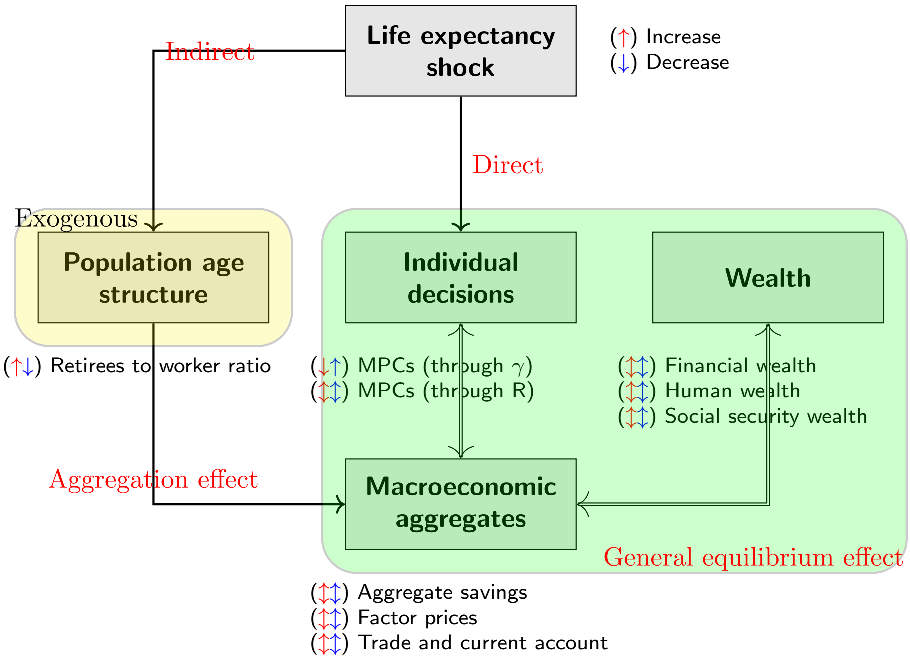


Figure 4: Effect of life expectancy shock

### 3.3 Determinants of emissions baseline and emissions mitigation effort

Previous studies have proposed several different indicators as a possible proxy to show a country's mitigation effort, such as energy and carbon prices, the energy intensity of economies, and the emissions reduction from a baseline (Aldy et al., 2016, 2017). By construction, energy and carbon prices and energy intensity of the economies are equal in all periods in this paper. However, baseline emissions projections, which determine mitigation efforts, are sensitive to whether one captures demographic dividends and spillovers through capital flows. Through capital flows, asymmetric demographic changes can increase emissions in one country while reducing them in the other country. Therefore, models that cannot capture spillovers can overestimate one country's emissions baseline while underestimating the emissions baseline of another country.

To understand the impact of demographic changes on emissions, let's look at the equations that determine total emissions in the economy. Only dirty (fossil) energy emits carbon. Total carbon emissions in a country are equal to carbon emissions per effective labor times its total effective labor force. For simplicity, this paper assumes only one type of fossil fuel. Therefore, the quantity of fossil energy use corresponds to total emissions in the economy. In response to a demographic shock, total carbon emissions in the economy change according to:

$$\Delta_t(O_t) = \Delta_t(o_t) + n_t^{wf\xi} \tag{16}$$

where big $O_t$ stands for total fossil energy use while small $o_t$ stands for fossil energy use per effective labor. As explained in section 3.1.1, $n^{wf\xi}$ represents growth in the effective labor force. Section 3.1.1 have already discussed demographic transitions impact on the effective labor force. With a falling fertility rate, an effective labor force can grow in the short run. The effective labor force will be larger relative to the workforce that does not consider its age composition in the long run. Therefore, models that do not take into account demographic changes will underestimate a country's total emissions from a larger effective labor force in the case of fertility reductions. On the other hand, because of changes in aggregate savings (assuming the country is a large economy and does not take the world interest rate as given), output per effective labor and consequently emissions per effective labor will also grow under a fertility reduction scenario. A lower interest rate will result in capital-intensive sectors expanding more. Because the energy sector is relatively capital intensive, emissions per effective labor will grow more than output per effective labor, as shown in Batsuuri (2020).

However, how much fossil energy use (or emissions) per effective labor changes for a country depends on the interest rate the country faces. Within a life-cycle model, the demographic structure is one factor that affects a country's aggregate savings rate. However, the factor prices a country faces depend on whether the country is open to capital flows from other economies or not and on how big the country is relative to the rest of the world. As discussed in Ferrero (2010); Eugeni (2015); Niemeläinen (2017); Batsuuri (2022) capital flows within life-cycle models depend on demographic and institutional differences that determine each countries' aggregate savings and investment patterns. In addition, unlike ILA models, trade imbalances can be permanent in a life-cycle model as there are no transversality conditions on a country's borrowing. In life-cycle models, the age structure of the population endogenously determines the steady-state values of capital per effective labor as highlighted by Ferrero (2005). Therefore, life-cycle models can generate different outcomes from ILA models in predicting capital flows between countries for different demographic outlooks. Because the energy and carbon intensity of economies are different (Emir et al., 2019), this has implications for global emissions. In addition, because of not accounting for negative (in the case of increased total dependency) or positive (in the case of reduction in total dependency) demographic dividends, the model could overestimate or underestimate the emissions baseline of countries for given demographic patterns.

# 4 Calibration and quantitative investigation

This section undertakes a hypothetical quantitative investigation to investigate the effect of an asymmetric fertility and longevity transition on aggregate savings and capital per effective labor within the model described in section 2. To focus on asymmetry and spillovers, only one of the countries undergoes a demographic shock. To bring the analysis closer to the real-world applications and understand demographic uncertainty scenarios on emissions baseline, section 4.2 uses demographic shocks obtained from demographic outlooks for China and the US under different probabilistic projections by the UN. Quantitative analysis in sections 4.1 and 4.2 is calibrated with parameter values commonly used in the literature. The values for the parameters used in the models in section 4.1 and 4.2 are provided in Table 1 to 3. Section 4.3 undertakes a sensitivity of the findings to key parameters that reflect differences in institutions across countries.

Table 1: Production parameters

| Parameter | Values | Description | Source |
|---|---|---|---|
| $\alpha$ | 0.667 | Labor share in the final output | |
| $\alpha_2$ | 0.380 | Labor share in the clean energy sector | |
| $\alpha_3$ | 0.500 | Labor share in the dirty energy sector | |
| $\Psi$ | -0.449 | $\frac{1}{1-\Psi}$ Elasticity of substitution between capital labor composite and energy | |
| $\varphi$ | -0.058 | $\frac{1}{1-\varphi}$ Elasticity of substitution between clean and dirty energy | |
| $\delta$ | 0.060 | Capital stock depreciation rate | |
| $v1$ | 0.960 | Share of capital labor composite in the final output | US EIA |
| $\eta_1$ | 0.800 | Share of dirty energy in the energy production | US EIA |

Table 2: Demographic parameters

| Parameter | Values | Description | Source |
|---|---|---|---|
| $\omega$ | 0.039 | Probability to retire | |
| $\theta$ | 0.048 | Probability to become mature worker | |
| $z$ | 0.045 | Probability to become young worker | |
| $\lambda_c$ | 0.278 | Time cost of children | Bloom (2017) |
| $\xi$ | 0.500 | Productivity of young workers compared to mature workers | NTA database |
| $\gamma_{ss}$ | 0.08 | Initial life expectancy | UN WPP 2019 |
| $n_{ss}$ | 1.01 | Initial growth rate of children | UN WPP 2019 |

Table 3: Household preferences and other parameters

| Parameter | Values | Description | Source |
|---|---|---|---|
| $\beta$ | 0.994 | Time preference rate | |
| $\sigma$ | 0.750 | Household intertemporal elasticity of substitution | |
| | 1.000 | Relative size of countries | Hypothetical |
| $x_{lss}$ | 1.01 | Productivity growth | Penn World Table 9.1 |
| $pen$ | 0.020 | Share of pension expenditure in GDP | |
| $by$ | 0.150 | Government debt to GDP ratio | |
| $gy$ | 0.150 | Government expenditure to GDP ratio | |

Continued on next page

**Table 3 – continued from previous page**

| Parameter | Value | Description | Source |
|---|---|---|---|
| *tax* | 0.050 | Share of wage for child | |
| $\zeta$ | 1.000 | Share of capitalized value of labor income of the young workers that can be borrowed | |

Continued on next page

## 4.1 Hypothetical shock with two countries

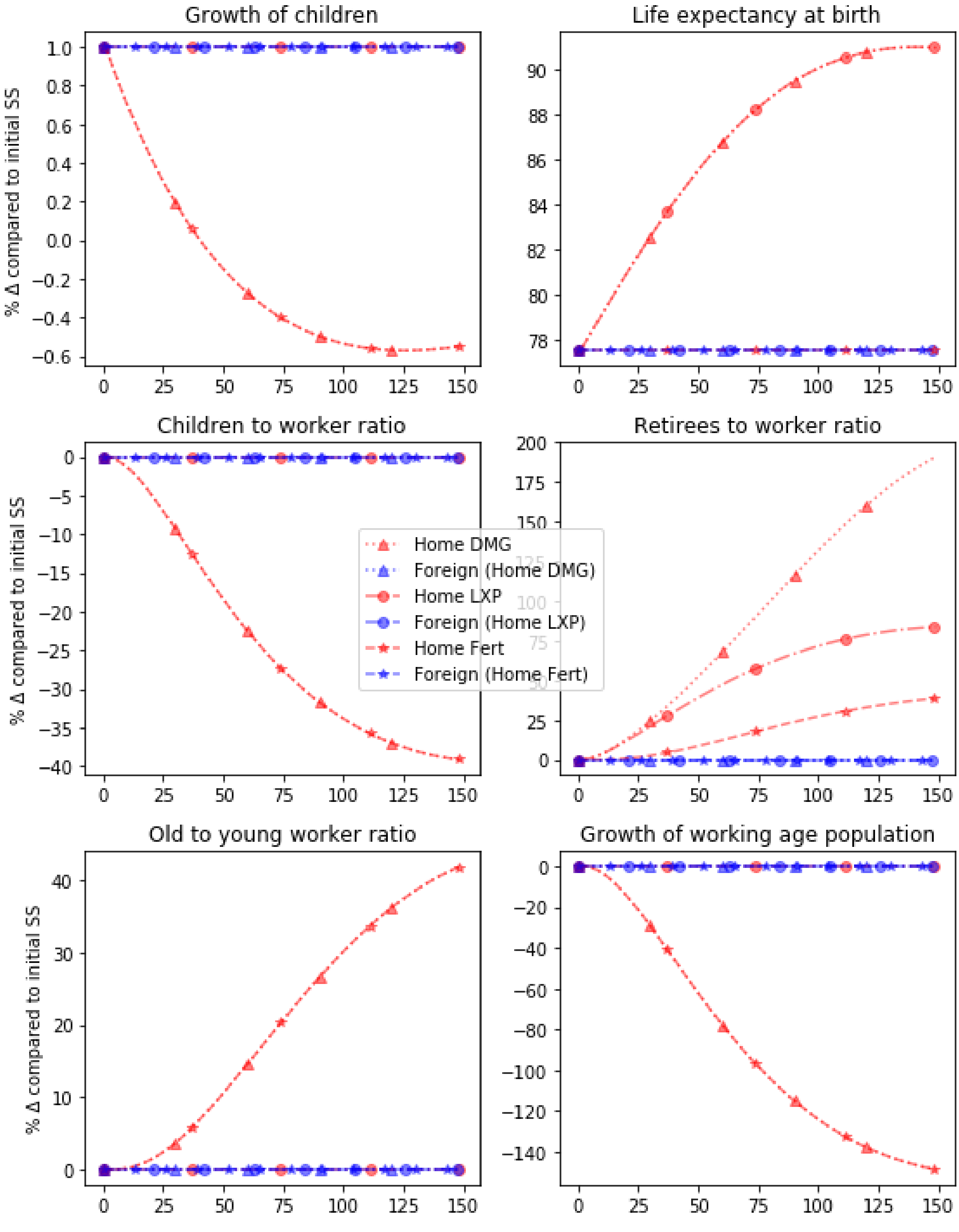
An asymmetric demographic shock is introduced into a hypothetical model of otherwise symmetric two countries, the home and the foreign. In the first scenario, called Fert, it is assumed that only the home country's fertility rate falls, causing the growth rate of children in the Home country to fall from 1% in the beginning to -0.6 % within a 100-year horizon. In the 2nd scenario, called LXP, it is assumed that only the home country experiences a reduction in its mortality rate after retirement, causing the life expectancy to rise from 78 in the beginning to over 90 years within a 100-year horizon. In a third scenario called DMG, it is assumed that the Home country experiences both the fertility and the life expectancy shock described in the Fert and LXP scenarios simultaneously.

Figure 5 contrast population dynamics in the home and the foreign country under the three shocks. Because there is no fertility and life expectancy shock in the foreign country, there is no change in population growth and population age structure in the foreign country. Only the fertility shock affects the children to worker ratio and the workforce's age structure for the home country. In contrast, the fertility and life expectancy shock affect the retirees to worker ratio. Furthermore, the growth of the working-age population is only driven by the fertility shock but not by increasing life expectancy after retirement. In figure 5, one can also see that both the reduction in fertility and increase in life expectancy after retirement drive up the retirees to worker ratio, which changes the most under both shocks introduced together.

Figure 6 contrasts individual savings decisions and the two countries' wealth distribution under the three scenarios. As explained in section 3.2, life expectancy shocks alter the MPCs of individuals directly in addition to their indirect effect due to changes in the interest rate. In contrast, fertility shocks only affect the MPCs through the interest rate change. The impact of interest rate on the MPCs moves in the same direction as life expectancy shocks on the MPCs, reinforcing its effect. In the second country (the foreign country), MPCs change only in response to interest rate changes.

Regarding the effect of the demographic factors in explaining wealth distribution, we can see interesting dynamics from the bottom two figures of figure 6. In the home country under the fertility scenario, young workers' share of wealth rises initially before declining. In contrast, the share of wealth held by young workers in the second country falls in a pattern similar to the interest rate changes. This contrasting result shows the importance of aggregation and the child dependency effect. There is no change in the relative size of different age populations in the foreign country. The relative decline in young workers' financial assets is driven by the change in factor prices, which start around 20 years after the fertility shock hits. Whereas in the

Figure 5: Asymmetric demographic transition scenario



home country, a reduction in the fertility rate immediately increases the relative financial wealth of the young workers by reducing transfer to children and releasing labor for work which more than offsets the negative effect of factor prices on the young workers' relative asset holdings. However, after a few decades, the aggregation effect dominates the child dependency effect. A reduction in the fertility rate causes the relative size of the retirees and the mature workers to increase, causing the share of wealth held by young workers to decline.

Figure 6: Divergence of savings rate and wealth holdings by different generations

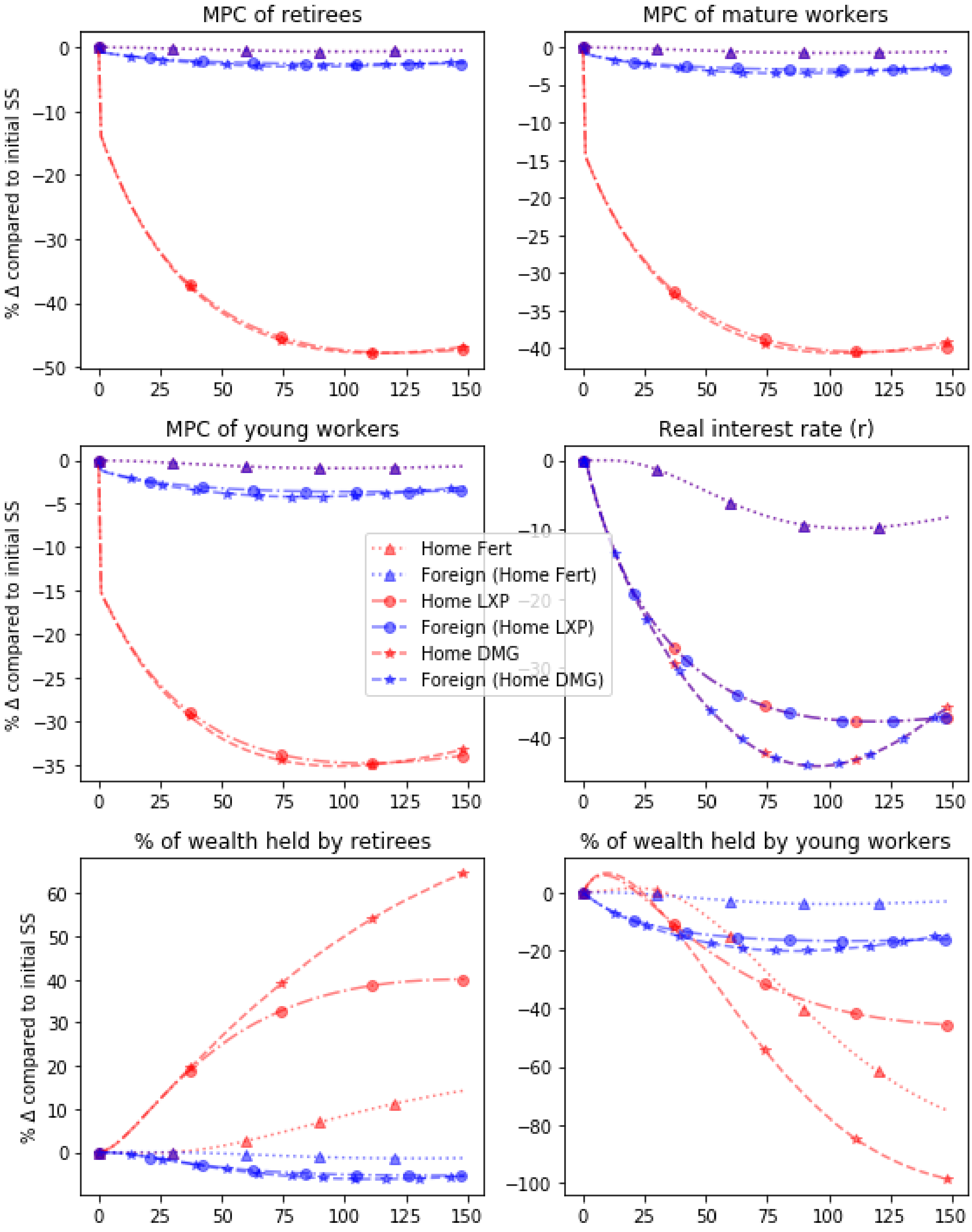
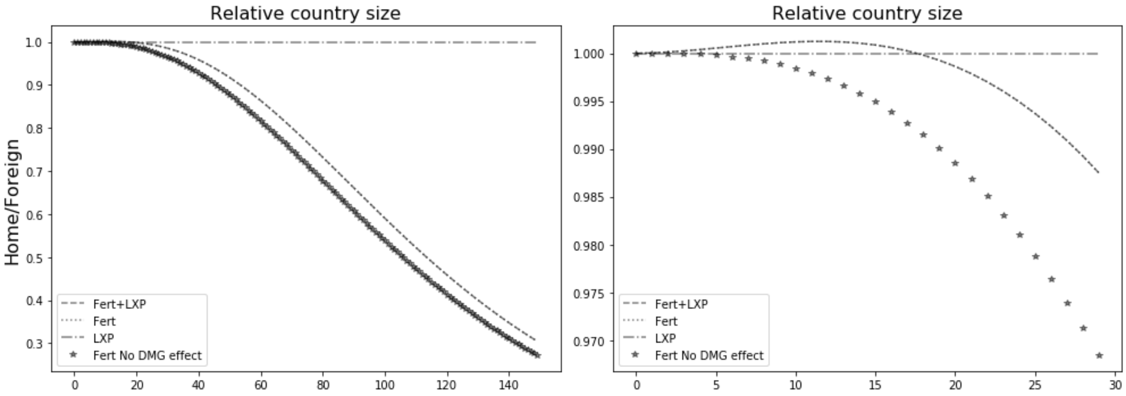


Figure 7: Relative country sizes



Under the LXP scenario, the share of wealth held by young workers declines in both countries. The magnitude of the reduction in the interest rate is such that the positive effect from the decrease in child dependency on the share of assets of the young workers is more than offset by the factor prices shown in the DMG scenario when the two shocks happen simultaneously. The negative effect of the factor prices on the share of assets held by the young workers is due to their different life horizons and wealth composition. Young workers have the longest life expectancy. In response to the reduction in the interest rate and the increase in life expectancy, young workers' MPCs decline the least compared to mature workers and retirees. Furthermore, the decline in the interest rate and increase in wages increase the capitalized value of the young workers' human wealth the most because they expect to stay in the workforce the longest.

Only fertility transitions drive changes in the relative country sizes, with the home economy's size compared to the second country falling to 30 % as shown in Figure 7. Furthermore, there is a marked difference between relative country sizes when one doesn't consider changes in the workforce's age structure and the workers' labor supply changes. The right panel of Figure 7 shows the relative country sizes with and without demographic effects for a 30-year horizon, while the left-hand side shows the same for a 150-year horizon. Models that do not consider demographic effects will underestimate the size of countries which are under a demographic transition relative to countries which are not under demographic transitions.

Demographic transition changes projected emissions for both countries linked through trade and capital flows. Figure 8 shows that the output and energy use is higher in both countries relative to a case where there are no demographic effects. However, once demographic effects are taken into account, the economy and emissions are lower in the open economy under the demographic transition than if the country was a closed economy. At the same time, the economy and emissions are higher in the country, not under any demographic changes than if the country was a closed economy. As highlighted in Batsuuri (2020), energy consumption grows faster than the output reflecting its capital intensity. An additional insight from an integrated model is that global emissions can be permanently different for two reasons. When countries are integrated, the global output is higher than if the countries were closed, showing the positive effect of exchange between the two countries with different domestic interest rates. Second, the impact on global emissions of this

Figure 8: Projection of output and energy use per effective labor

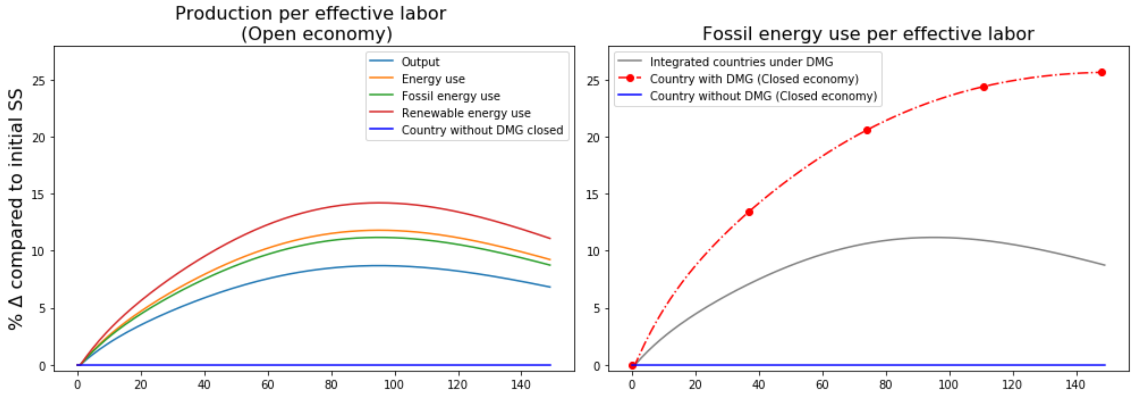
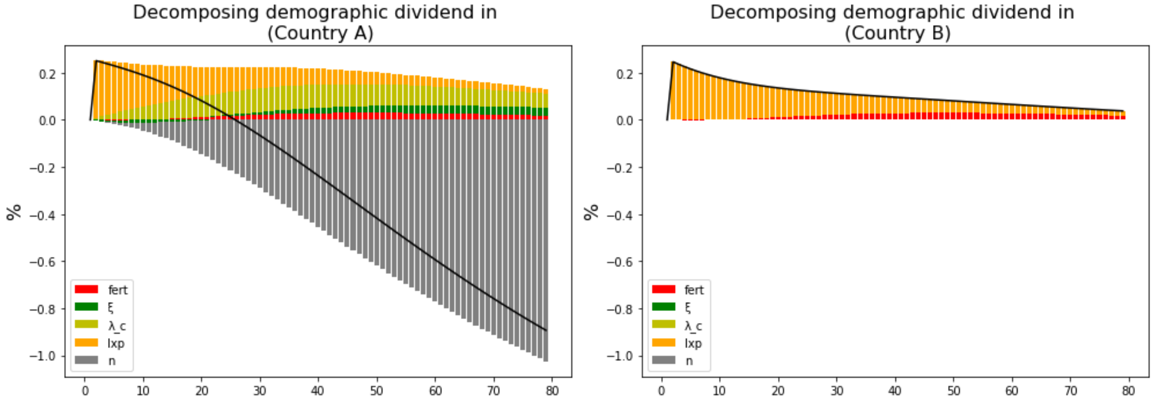


Figure 9: Changes in aggregate economic growth



reallocation of output across countries depends on the economies' carbon intensity. If the two economies' carbon intensities are very different, the spillovers can change global emissions.

Figure 9 shows the change in annual growth of aggregate output of the Home and the Foreign country compared to their initial long-run values. Because the demographic shock in our model is minimal, its effect on aggregate growth in a specific year is small. However, even small differences can accumulate into a larger difference in the projected outcomes over a longer horizon. The black line in figure 9 shows the net demographic effect. Models which cannot capture demographic dividends will underestimate the growth of a country under declining fertility and increasing longevity. At the same time, one can also underestimate or overestimate growth in countries that do not have demographic changes if one doesn't account for cross-country spillovers due to demographic differentials across countries.

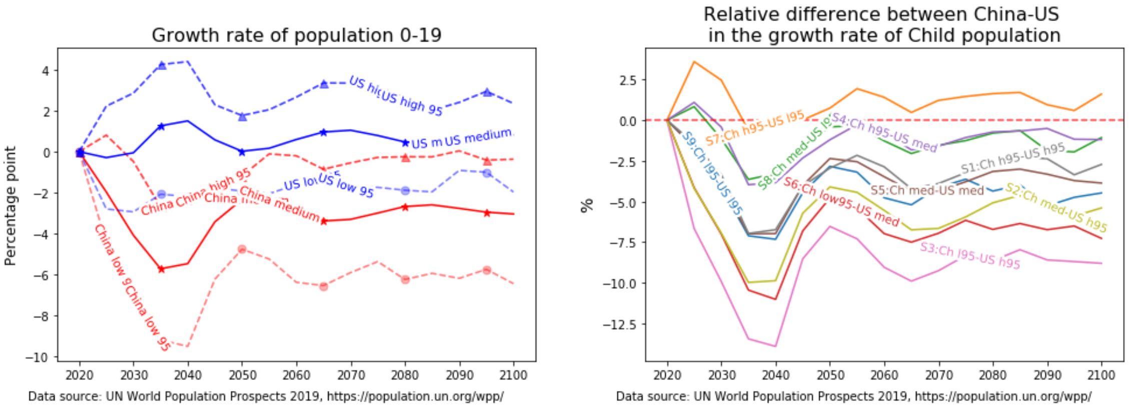
## 4.2 Uncertain demographic outlooks

This section examines nine different relative fertility and mortality change scenarios based on the US and China's three different probabilistic demographic outlooks. This section aims to understand the uncertainty around countries' emissions paths and emissions spillovers due to uncertainty around demographic differences across countries. Using demographic outlooks for China and the US, two large countries closely linked with trade and capital flows, makes the shock magnitude closer to reality.

### 4.2.1 Fertility rate and emissions baselines

Relative fertility scenarios are constructed by combining three different probabilistic projections for each country. Scenarios reflect fertility changes with varying asymmetries of magnitude across countries where scenarios four (S4), seven (S7), and eight (S8) are the least asymmetric while scenario three[20] (S3) is the most asymmetric, as shown in figure 10. Figure 10 shows that the fertility patterns may unfold quite symmetrically (S7 shows almost no difference in the growth rates of the populations under 19),but it is more likely that the fertility changes will unfold asymmetrically (i.e., there are many more scenarios where the relative difference is not zero).

Figure 10: Demographic outlook for China and the US



Growth rate of population 0-19

Data source: UN World Population Prospects 2019, https://population.un.org/wpp/

Relative difference between China-US in the growth rate of Child population

Data source: UN World Population Prospects 2019, https://population.un.org/wpp/

Figure 11 estimates demographic effects from nine different scenarios for Country A (which has a fertility shock that mimics China). Blue, green, and cyan-colored lines show the effect of demographic changes on the annual growth of GDP, with the value shown on the right axis. In contrast, the red, yellow, and purple lines show the cumulative growth effect of demographic changes with the value on the left axis. The lines with the same colors in 11 represent the same fertility shock in Country A combined with three different possible fertility shocks in country B (which has a fertility shock that mimics the US). Figure 11 shows few interesting results. First, demographic changes have a non-negligible impact on economic growth and emissions both in the short and long-run, which the models without demographics cannot capture. Second, the magnitude of the demographic effect depends on the magnitude of demographic shocks (in this case, the fertility shock), as shown by the variation between lines with different color. Third, the magnitude of the demographic effect depends not only on the country's demographic changes but also on the demographic changes of its trading partners, as shown by the difference between lines with the same color. Fourth, even if the demographic effect is small in a

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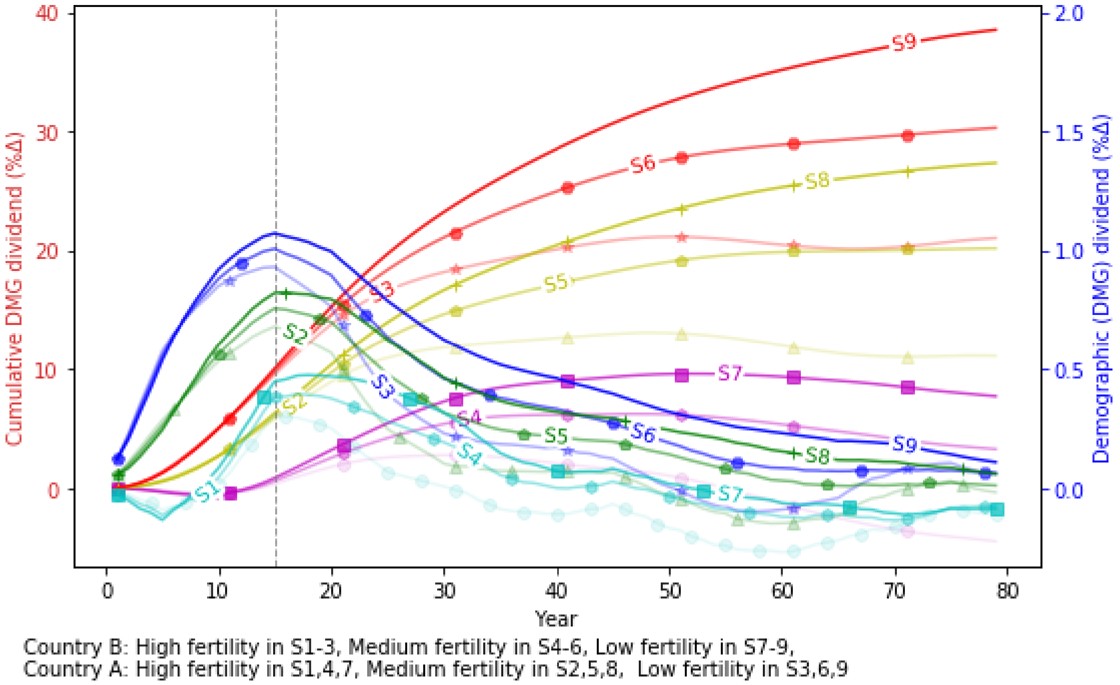
[20] Scenario three (S3) is where country A follows a low fertility scenario similar to China's 95th percentile low fertility path while Country B follows a high fertility path that is similar to US's 95th percentile high fertility path.

given year, it can accumulate over many years to cause large disparities in projected outcomes, as shown by the difference between the lines with same colors showing cumulative effects.

Figure 11: Demographic dividends under a fertility shock (Country A)



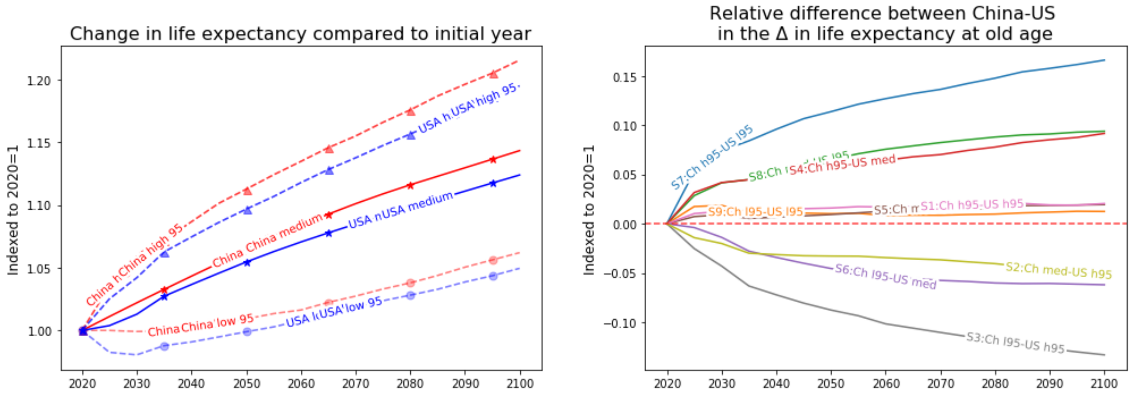
Country B: High fertility in S1-3, Medium fertility in S4-6, Low fertility in S7-9,
Country A: High fertility in S1,4,7, Medium fertility in S2,5,8, Low fertility in S3,6,9

### 4.2.2 Life expectancy and emissions baselines

Similar to the fertility scenarios, nine different relative mortality change scenarios have been constructed by combining three different mortality change scenarios for both China and the US as shown in figure 12. Unlike the fertility scenarios, which tilted toward China having lower fertility rates than the US, relative differences in mortality may be positive or negative. In other words, the odds that US life expectancy increases more than Chinese life expectancy are the same as the odds that life expectancy in China increases more than the life expectancy in the US (see 2nd panel of Figure 12).

Figure 13 shows both the annual and cumulative growth effect in Country A based on nine different life expectancy scenarios. Similar to figure 11, lines with same color represent the same life expectancy change of Country A combined with three different life expectancy changes in country B. Blue,green, and cyan lines show the annual growth effect with the value shown on the right axis. Red, yellow and purple lines show cumulative growth effects with the value shown on the left axis. Compared to fertility shocks, changes in life expectancy (as projected for China and the US) have only minor impacts on a country's annual and cumulative growth rate. Again this is also because it is assumed that the life expectancy at old age affects the economy only through changes in savings. If there are employment impacts of life-expectancy changes, such as longer labor force participation by the retiree population, there will be a larger demographic dividends from the changing life

Figure 12: Demographic outlook for China and the US

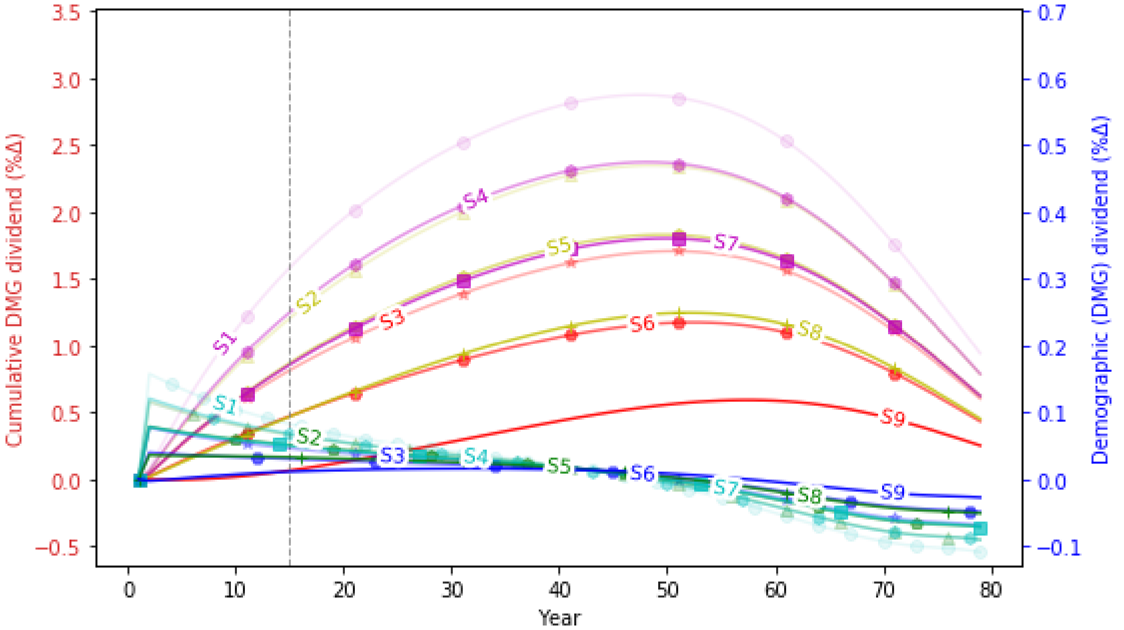


Change in life expectancy compared to initial year

Relative difference between China-US in the Δ in life expectancy at old age

expectancy at old age. Similar to fertility scenarios, the magnitude of the impact of the life-expectancy changes on annual and cumulative growth depends not only on a country's life expectancy changes but also on its relative life-expectancy changes, as shown by the variation between lines with the same color.

Figure 13: Demographic dividends under a longevity scenarios (Country A)



Country B: High Life expectancy (LXP) in S1-3, Medium LXP in S4-6, Low LXP in S7-9,
Country A: High LXP in S1,4,7, Medium LXP in S2,5,8, Low LXP in S3,6,9

### 4.2.3 Spillovers and emissions baselines

To further highlight spillover effects, this section focuses on two scenarios. Figure 14 shows the effect of demographic changes under scenarios three (S3) and nine (S9) for both countries under closed and open economy assumptions. S3 and S9 represent the same demographic change for Country A each combined with a different demographic changes for Country B. Specifically, S3 is the most asymmetric in terms of fertility changes across the two countries. This is shown in panel B of figure 10. In S3, Country A follows its low fertility scenario while Country B follows its high fertility scenario. When country B follows its high fertility path as in scenario 3, there is a capital dilution effect wherein high growth in the population under 19 depresses savings while more younger workforce reduces capital per effective labor. As shown in figure 14, due to the capital dilution and an increase in the interest rate, fossil energy use per effective labor also declines. In contrast, in S9, both countries follow their low fertility scenarios. In S9, low fertility in both countries bring larger demographic dividends and a bigger decline in interest rate, which explains the increase in fossil energy use per effective labor.

Figure 14: Emissions baseline (Open vs Closed economy)

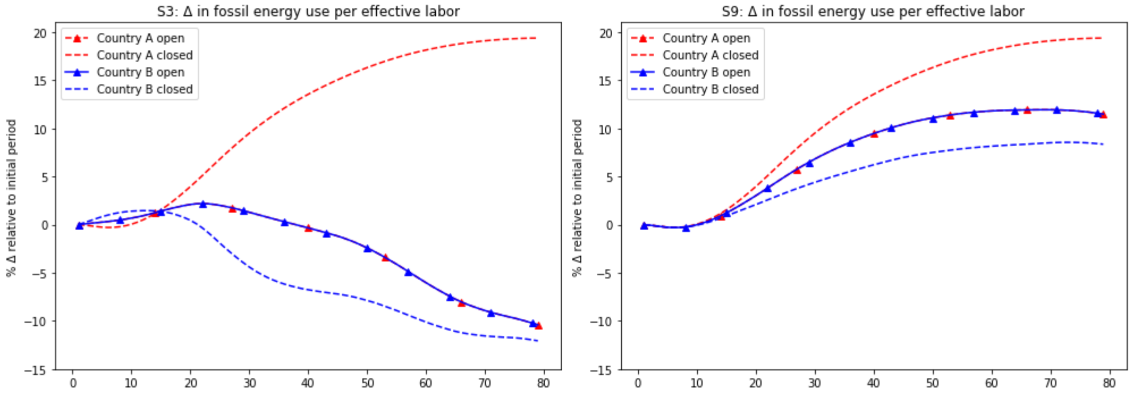
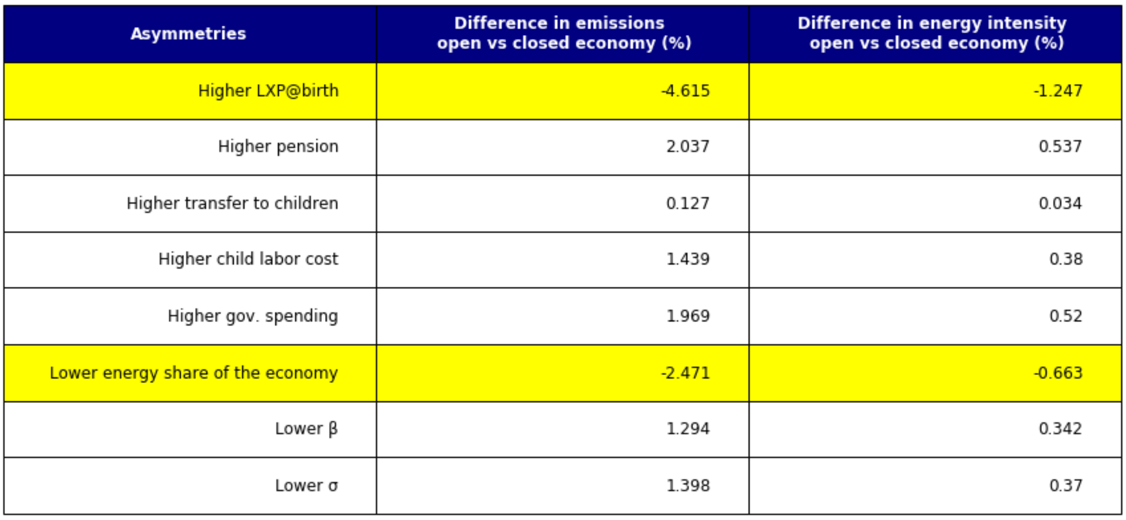


Figure 14 shows three results. First, a change in a country's emissions baseline depends on whether the country is an open economy or closed economy, based on the apparent difference between emissions per effective labor across open and closed economy assumptions under both scenarios. Second, when a country is an open economy, its emission baseline depends on its demographics and its trading partners' demographics. Figure 14 shows a significant difference in emissions per effective labor for Country A in S3 and S9 despite Country A having the same demographics in both cases. Third, the magnitude of the demographic changes on emissions baselines depend on the magnitude of demographic changes as well as asymmetries between countries. In other words,in addition to their impact on population scales, demographic changes affect emissions baselines through demographic dividends and capital flows which is most often neglected by models which do not explicitly include demographic changes.

## 4.3 Sensitivity analysis: Institutional and other asymmetries

Next, the two-country model's steady-state is solved under different model parameters to reflect initial asymmetries between countries. Considered asymmetries included differences in life expectancy, institutions such as pension, consumption and time cost of children, government spending, production (energy share of GDP), and preference parameters (subjective time preference rate, elasticity of intertemporal substitution). The previous literature (Ferrero, 2010; Niemeläinen, 2017; Eugeni, 2015; Batsuuri, 2022; Buiter, 1981) have found these differences to be important in explaining the persistent trade and current account imbalances across countries.

Figure 15: Emissions under various asymmetries



| Asymmetries | Difference in emissions open vs closed economy (%) | Difference in energy intensity open vs closed economy (%) |
|---|---|---|
| Higher LXP@birth | -4.615 | -1.247 |
| Higher pension | 2.037 | 0.537 |
| Higher transfer to children | 0.127 | 0.034 |
| Higher child labor cost | 1.439 | 0.38 |
| Higher gov. spending | 1.969 | 0.52 |
| Lower energy share of the economy | -2.471 | -0.663 |
| Lower β | 1.294 | 0.342 |
| Lower σ | 1.398 | 0.37 |

Figure 15 shows the difference in total emissions and energy intensity of the output of a country relative to its value under a closed economy assumption for each case listed in the column 'Asymmetries'. Everything else equal, the country with a higher life expectancy and a lower energy share of the economy relative to its trading partners will have a positive foreign asset position and negative trade balance in the steady-state. Longer life expectancy causes the country to have higher savings in anticipation of a longer retirement period, some of which is invested in foreign assets. Similarly, the lower energy share of the economy implies that it's labor share is higher than its trading partners, which allows for higher savings and positive foreign asset positions. In turn, positive foreign asset positions imply that, in the long run, the country can consume more than its domestic production. Therefore, emissions in the open economy with longer life expectancy and lower energy share of the economy can result in lower emissions for the country in the long-run relative to the case if the country had to invest all its savings domestically. In contrast, all else equal, countries with higher pension, higher consumption and time cost of children, higher government spending, lower subjective time preference rate[21] and lower elasticity of intertemporal substitution[22] will have lower aggregate savings compared to its trading partners and hence negative foreign asset position and positive trade balance in the long run. Everything else equal, higher government spending does not crowd out private spending one to one reducing aggregate savings as emphasized in Ferrero (2010). On the other hand, lower pension expenditure reduces tax on labor income for pensions under the pay as you go (PAYG) pension scheme. Because of the mechanisms mentioned in section 3, a reduction in the taxes increases aggregate savings. Eugeni (2015) has investigated the effect of an asymmetric pension scheme on aggregate savings and trade imbalance between countries using a two-period theoretical OLG model. She further provided empirical evidence that supports her

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[21] implying higher discounting of the future

[22] implying lower preference to smooth consumption across time

theoretical predictions that a country with lower PAYG pension coverage will have a positive foreign asset position (Eugeni, 2015). A negative foreign asset position and positive trade balance imply higher national emissions in the long run than if the country was a closed economy.

In addition, relative differences in consumption and time cost of children can affect a country's trade and foreign asset position, which Batsuuri (2022) explores in detail. Reduction in transfer to children reduces the tax on labor income and reduces the time cost of raising children, thereby increasing labor supply and income. Because Ricardian equivalence does not hold in this economy due to finite work and lifetime, children's consumption has a non-negligible effect on aggregate consumption and savings. Therefore, everything else equal, higher transfer to children and higher time cost of children causes a country to accumulate foreign debt and increase its output (positive impact of lower interest rate) and long-run emissions.

# 5 Conclusion

There is a growing need for economic models to evaluate and successfully implement climate change agreements. To successfully implement the Paris Agreement, the latest global policy agreement on climate change, economic models will be required to compare countries' emissions mitigation efforts which will help push countries to have more ambitious policies. Despite using multiple distinct models to increase the robustness of the studies to alternative assumptions, modelers continue to neglect the effect of demographic transitions on economic and emissions projections by not using life-cycle models, the main framework to study the impact of demographic changes.

Life-cycle models will be fundamental given the considerable uncertainty around future population patterns across countries. This paper investigates the robustness of the carbon emissions baseline to alternative demographic assumptions using a two-country life-cycle model with realistic demographic scenarios. Specifically, the paper constructs nine different demographic scenarios by combining low, medium, and high probabilistic projections of fertility and mortality rates of the two largest economies (China and the US). This paper shows that a country's emissions baseline is sensitive to its domestic and trading partner's demographics.

The model used in this paper has several advantages over previous modeling studies. First, because the model is solved in annual frequency, thereby capturing the effect of changing child and old-age dependency rates and the age structure of the workforce on aggregate savings and labor force growth both in short and the long run. Second, two-country features enable the model to capture spillover impacts from asymmetric demographic changes. Third, the inclusion of an energy-dependent production function allows for the examination of the impact of changes in factor prices on final output and energy and emissions, with each having different capital intensities.

The analysis in this paper leads to two main results. First, the impact of demographic changes on emissions can be large depending on projected fertility and mortality patterns. Models which cannot capture demographic dividends associated with changing age-structure of the population following fertility and mortality changes can underestimate a country's emissions baseline for fertility reductions and overestimate a country's emissions baseline for increased fertility. Annual change in economic growth due to demographic dividends can be small. Still, demographic dividends can accumulate over many years, causing significant differences in the long run with implications for climate economy models that deal with long-run projections.

Second, relative demographics and institutions can determine capital flows between countries within life-cycle models. Therefore, differences in the demographic outlooks across countries can affect cross-country capital flows and resulting emissions. This paper shows that the size of cross-border capital flows depends on how asymmetric the demographic changes will be across countries. Models which do not take into account spillovers can overestimate (underestimate) a country's emissions baseline with relative decline (increase) in its fertility and mortality rates. Furthermore, differences in governmental and household institutions such as pensions and social security system, time and labor cost of children, and energy intensity of the economies will amplify the effect of asymmetric demographic changes. As long as the economies' carbon intensities do not converge, global emissions will significantly differ from what they would have been if the effect of the demographic shocks was contained domestically.

The interconnected emissions trajectories of different countries through capital flows, as determined by demographic differences, illustrates the difficulty in comparing carbon emissions mitigation efforts using a model that is not well suited to capture the demographic dividends and associated spillovers. Through capital flows, asymmetric demographic changes can increase emissions in one country while reducing them in the other country compared to a baseline that does not consider the spillover impact. Hence, the rankings of countries' emissions mitigation efforts' may change if one uses life-cycle models. In addition, life-cycle OLG models provide different implications from the standard models on many fronts, including the effect of government debt and deficit on savings and the persistence of trade and current account imbalances. Therefore, to increase robustness, this paper suggests using life-cycle models in studies that intend to compare countries' mitigation efforts and proposes a suitable modeling framework.

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