Population age structure as a determinant of long-run macroeconomic growth: demographic endogenous growth theory

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POPULATION AGE STRUCTURE AS A DETERMINANT OF LONG-RUN MACROECONOMIC GROWTH

Demographic Endogenous Growth Theory

Abstract

Just as human age is a key determinant of individual economic productivity, a population's age structure is a significant causal factor of economic productivity and growth. This paper attempts to update the traditional theories of economic growth by incorporating demographic transition theory and intergenerational transfers into long run economic growth. Whereas contemporary theory interprets the *demographic dividend* as a transitory and uncertain exogenous stimulant to economic growth, this paper will attempt to demonstrate that age structure is instead a persistent and endogenous determinant of economic productivity. In addition, the paper will argue that a significant portion of modern and ancient economic divergence can be explained by variations in age structure. These findings will have important implications for policymakers and researchers interested economic development.

Keywords: **Demographic Economics, Economic Growth, Economic Theory, Macroeconomics, Quantitative Methods**

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Chapter I: Introduction

Cum essem parvulus, loquebar ut parvulus, cogitabam ut parvulus. Quando autem factus sum vir, evacuavi quæ erant parvuli

The modern understanding of the macro relationship between age structure and economic expansion is primarily informed by the demographic dividend hypothesis (Bloom, Canning, & Sevilla, 2003). The contemporary interpretation of this dividend hypothesis is that a maturing population grants a society a *window of opportunity* to take advantage of this changing age structure and augment economic growth. The hypothesis also asserts that changes in age structure do not have a guaranteed causal effect on macroeconomic productivity and that this dividend must first be harnessed through the right economic policies and institutions. In effect, this interpretation posits that changing age structure as an exogenous and transitory economic stimulus dependent on other social factors.

In contrast, this paper will make the case the impact of this change in age structure is in fact quite substantial, endogenous in nature and guaranteed. This is a consequence of human physiology and social norms around labour time across age. Adults are manifestly more economically productive than non-adults (Skirbekk, 2004) and their labour participation rates are persistently higher. In the long term, the share of adults in the population functions as a harbinger for the ratio of workers per capita. Essentially, age structure is a persistent and endogenous causal economic force. Moreover, the paper will argue that it is precisely these disparities in age structure that explain a significant proportion of economic variation today and throughout history.

The core of this paper's Demographic Endogenous Growth (DEG) Theory is incapsulated in the following four propositions:

Proposition I: The higher the proportionate adult population, the higher the economic output per capita, *ceteris paribus*.

Proposition II: The higher the proportionate adult population, the higher the rate of economic growth, *ceteris paribus*.

Proposition III: The demographic transition, the core mechanism through which age structure evolves, is also an economic transition.

Proposition IV: A statistically significant proportion of historic and current human economic variation can be explained by differences in age structure as influenced by disparities in demographic transition rates.

This paper will substantiate these propositions and their implications through mathematical induction based on the axioms of neoclassical macroeconomic theory. This will be further validated using empirical methods.

In Chapter II, the underlying model and principles will be developed, as well as a more formal articulation and proof of the first two Propositions. This model, the Lee-Mason model, will then be incorporated into neoclassical and some heterodox macroeconomic growth frameworks.

Chapter III offers a short technical treatise on age structure and its various sub-components. The chapter will also highlight the role of time allocation and its broader impact on economic productivity.

Chapter IV covers the empirical analysis and offers a review of the existing empirical studies exploring the relationship between age structure and economic development. The chapter also validates this theoretical framework through a stochastic process.

Chapter V explores policy implications focusing on migration and fertility. Emphasis will be placed on the latter, which will be assessed through the lens of feminist economics. A feminist critique of the underlying fertility regime is also synthesised.

Chapter VI reviews the overall theory, pointing out various limitations of the theory and areas requiring further research.

Chapter II: Theory

Διηνεκῶς καὶ ἐπὶ πάσης, εἰ οἷόν τε, φαντασίας φυσιολογεῖν, παθολογεῖν, διαλεκτικεύεσθαι

The theoretical foundations of how age structure interacts with the economy begin with the work of Allais and then Samuelson from in the mid-1900s (Samuelson, 1958), (Samuelson, 1976) and (Arthur & McNicoll, 1978). Thereafter, a body of work spearheaded by Bloom and Williamson (Bloom & Williamson, 1998) spawns the concept of the *demographic dividend* (Bloom, Canning, & Sevilla, 2003). However, it is arguably the works of Drs Andrew Mason and Ronald D. Lee that have advanced the most granular insight into this field of generational economics (Lee R. D., 1994) (Lee, Mason, & Miller, 2003) (Clark, Ogawa, & Mason, 2007) (Lee & Mason, 2010) (Mason, Lee, & Lee, 2010) (Mason & Lee, 2012). This voluminous body of literature is what has inspired and supplemented much of this paper. Henceforth, the model developed in this paper, and this chapter specifically, is termed the *Lee-Mason (LM) model*.

The LM model can be articulated with the illustration in **Figure 1**. Economic production is the domain of adults, consumption is universal across age, and the demographic age structure determines the ratio of net producers to net consumers.

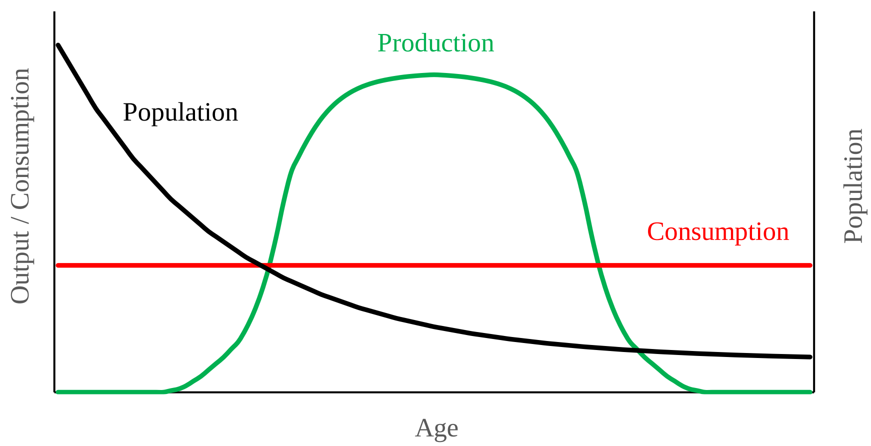


Figure 1*: Illustration of how individual economic production, consumption and population vary across age.*

Macroeconomic Intergenerational Framework

Using the principles of Intergenerational Transfers (Kotlikoff & Summers, 1981) (Lee R. D., 2013) (United Nations, 2013), humans can be said to experience three distinct phases with respect to age, consumption and production:

1. **Development Phase:** From birth to young adulthood, humans are still developing towards physiological maturity. Labour time is limited during this phase given the deleterious health impacts of child labour (Ibrahim, Abdalla, Mohammed, Abdelgadir, & de Vries, 2019) and the positive impact of education on economic growth (Hanushek & Woessmann, 2007). Therefore, more time is allocated towards the productivity-enhancing consumption, namely education, in preparation for the subsequent production phase. During this phase, consumption exceeds production, and humans rely on a range of public and private intergenerational transfers from households and other institutions.

2. **Production Phase:** During this phase, humans allocate more time towards production. As this labour time increases, production eventually exceeds consumption. Working economic agents will earn income through this phase as private workers (labour income), asset owners (capital income) and government personnel (tax). This income is then channelled towards consumption and savings:
    a. Consumption needs are met for themselves and other humans typically in the Development and Senescence phases. These intergenerational transfers occur across various institutions as well. For example, governments provide education in the form of state-sponsored schools for agents in the production phase. Adults can also fund the consumption needs of capital-owning seniors through dividends, rents, interest and the like.
    b. Savings effectively represent deferred consumption and are channelled towards the acquisition of production-enhancing capital through investment.

    Assume that consumption needs are Maslowian in nature with autonomous consumption taking priority over discretionary expenditures. This basic feature of the framework explains how when production time is limited, economic growth could plausibly stagnate as production is diverted towards consumption, leaving very little for capital accumulation. A *demographic poverty trap* of sorts. This is a key insight that will be revisited in discussion of the Propositions I and II. This result is also consistent with the observed economic stagnation of the Malthusian Epoch (Quamrul & Galor, 2011).

3. **Senescence Phase**: this phase is typically marked by the deterioration in human physical and cognitive fitness (Amarya, Singh, & Sabharwal, 2018). During this transition, economic agents revert to being net consumers as their consumption once again exceeds production. Humans in this phase will hence increasingly rely on intergenerational transfers to bridge their consumption gap.

The framework is summarised in **Figure 2**.

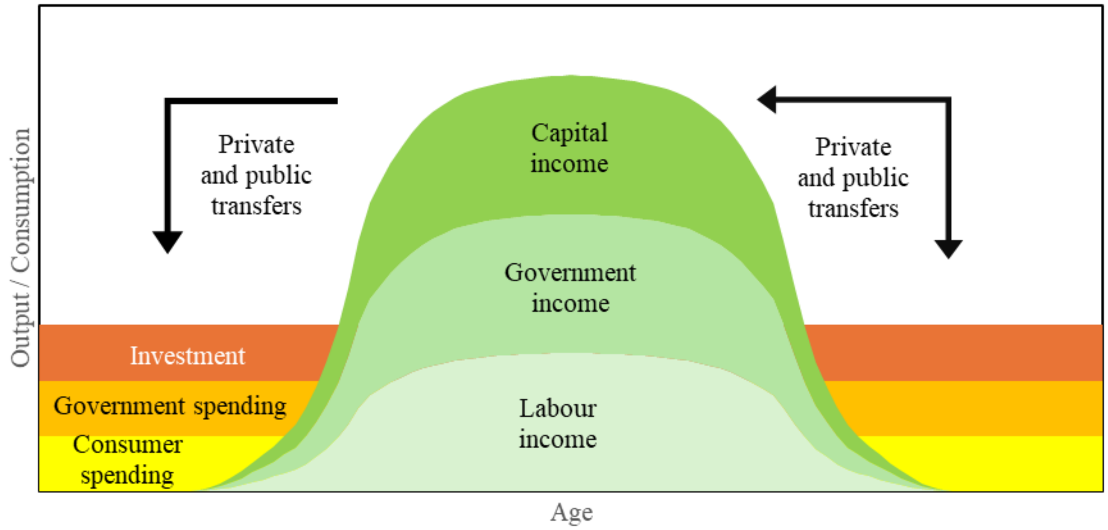


Figure 2*: The Macroeconomic Intergenerational Framework illustrates how aggregate production, consumption and intergenerational transfers vary across age*

The relative sizes of these aggregates, as well as the axes scales, are not empirically precise. Children for example, tend not direct investment expenditures.

Production and Consumption

The Age Production Function (APF) refers to the aggregate economic output frontier across human age. It is effectively GDP by age, as per the Macroeconomic Intergenerational Framework. The APF is, by definition, a more precise measure of *active* economic production as it captures the direct expenditure of labour time by workers. The APF hence excludes intergenerational passive income. This is advantageous given that, as the only active factor of production, labour is effectively the ultimate source of all economic output. All passive income such as rent, dividends, taxes and profits rely on the active production time of workers[1].

The National Transfer Accounts (NTA) Project (https://ntaccounts.org) offers arguably the most robust dataset of active economic production and consumption across age. Covering over 60 countries, the NTA project tracks how active economic output is rewarded through wages across age and subsequently consumed and transferred to other humans in the Development and Senescence Phases.

[1] This is loosely consistent with some aspects of the Marxian labour theory of value. A capitalist employer, regardless of their entrepreneurial endowments, still only has 24 hours of labour time a day; a pittance compared to the total daily production hours availed by the employees. Aggregate production comes from workers. Capital owners and the government merely extract their share.

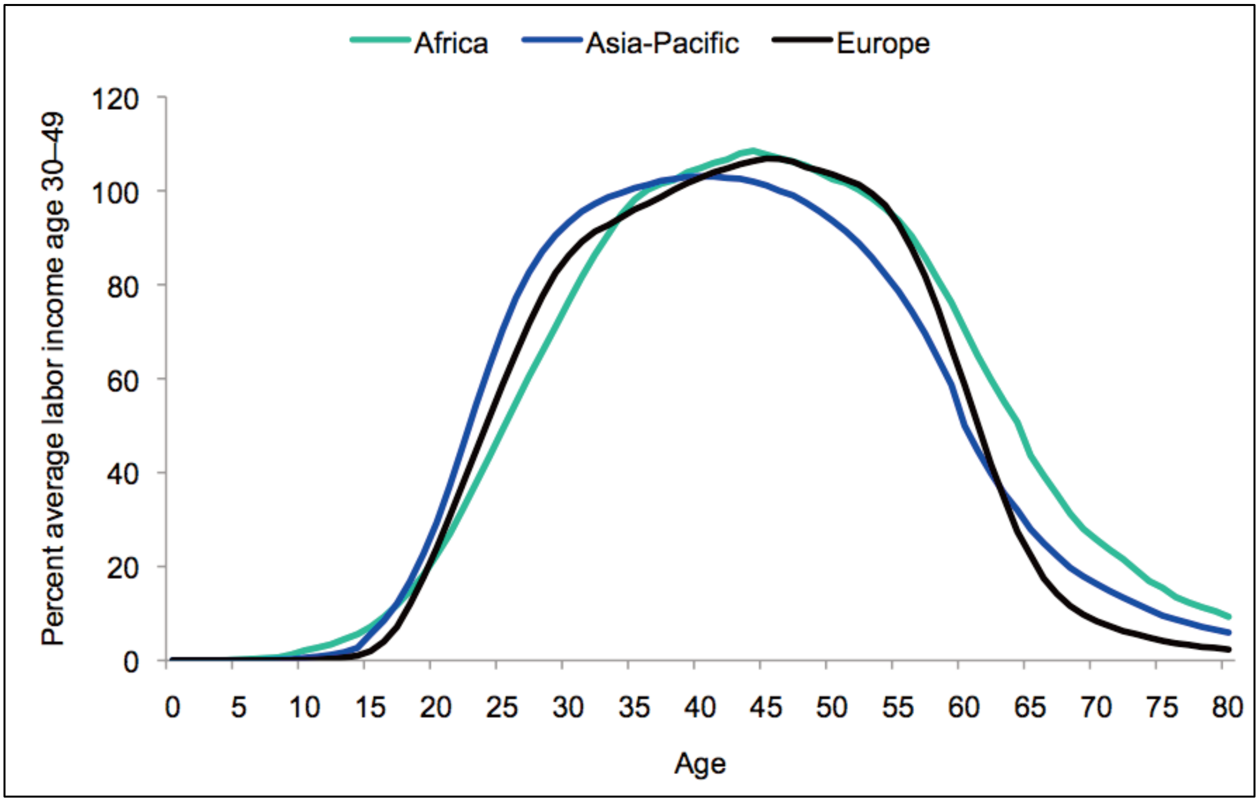


Figure 3: *Normalised labour income across age for selected regions | Source: NTA Project*

The chart in **Figure 3** is consistent with the theoretical framework laid out earlier and illustrates the consistency of this relationship across diverse regions.

Due to variation in legislation, culture, educational attainment and the like, it is unlikely that any two separate human societies possess identical APFs. Indeed, it is also unlikely that the APF is precisely identical for the same population through even adjacent time periods. That is, the function is not strictly homogenous. Rather, it is stochastic in nature but likely exhibits weak stationarity especially when analysing the function's moments over longer periods of time. In more plain language, it is a wobbly curve but with a long run pattern.

Drawing on this foundation, the APF at time t, $Y_t(x)$, is therefore estimated to be a stochastic, unspecified and concave distribution exhibiting global maxima within the 25 to 55 age cohort. And let $y_{t,x}$ represent the total output produced by a unit of labour aged x at time t with ω as the maximum human age.

The Age Consumption Function (ACF), $C_t(x)$, is relatively more straightforward to estimate. Unlike production, consumption is continuous across age but with variations. For the sake of simplicity however, the model assumes that aggregate consumption is constant across age. Empirically however, the relationship is much noisier. For example, young and elderly cohorts may impose a consumption spike due to the comparatively high education and healthcare costs they incur as illustrated in **Figure 4**.

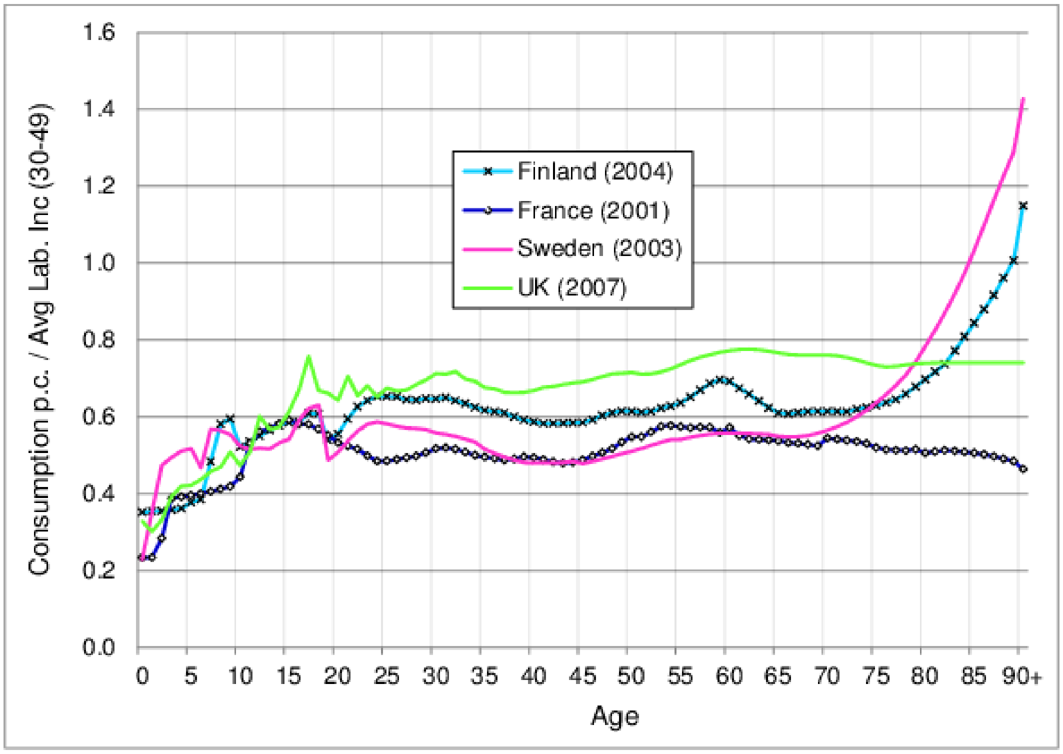


Figure 4: *Normalised consumption across age for selected countries | Source: Prskawetz, Sambt (2014)*

As with the APF, $c_{t,x}$ represents the total consumption, which excludes savings, by the human cohort aged x at time t.

Figure 5 illustrates the consolidation of these functions.

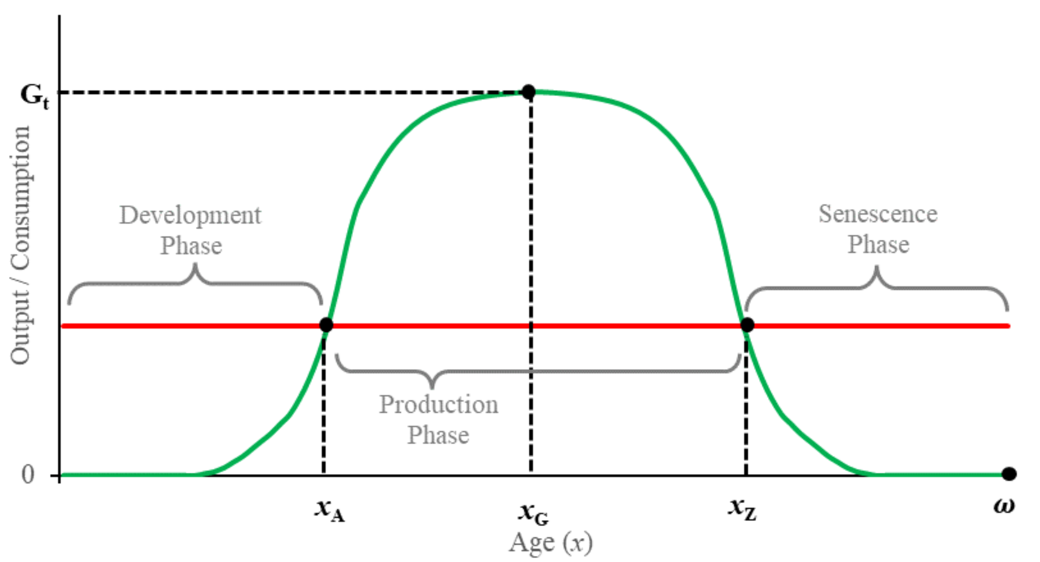


Figure 5: *Illustration of the Macroeconomic Intergenerational Framework showing the 3 economic lifecycle phases of economic agents (development, production & senescence). Agents enter and exit the production phases at ages x_A and x_Z respectively, maximising their lifecycle income/production of G at age x_G before expiring at age ω.*

x_A represents the age at which economic agents will begin to produce more than they consume. This is when humans transition from the Development Phase into the Production Phase. This typically occurs in the 20s, around the same period when myelination, the final stage of human brain development, occurs (Tierney & Nelson, 2009).

x_G represents the age when humans achieve peak lifetime output (and income) of G_t which is also the global maximum of APF function.

x_Z represents the age at which consumption once again begins to exceed productive capacity income declines and humans transition to the Senescence Phase.

ω represents the maximum human lifespan.

Age Structure

For much of human history, age structures resembled a classic population pyramid (Kingsley, 1945). The typical human society has had a relatively large share children compared to adults and the elderly. Mortality rates have historically been a function of disease burden (Mathers, Boerma, & Ma Fat, 2009) which hasn't been uniform across the world (Guernier, Hochberg, & Guegan, 2004). Pathogenic richness, and therefore disease burden, is higher around the tropics and in Africa specifically (Dunn, Davies, Harris, & Gavin, 2010) (Han, Kramer, & Drake, 2016) (Wood, McInturff, Young, Kim, & Lafferty, 2017), where modern humans originated from (Tattersall, 2009). Therefore, mortality rates likely declined as modern humans exited Africa around 80,000 years ago and colonised other parts of Earth. With lower mortality came lower birth rates as humans needed fewer children to maintain their societies. This *archaic demographic transition* possibly occurred over many years as humans migrated across the planet. It would help explain why Africa's human population has persistently been relatively low despite being the geographic origin of modern anatomical humans.

The *modern demographic transition* begun in the nineteenth century as advances in healthcare and hygiene spurred a swift reduction in death rates (Coale, 1989). As death rates and fertility rates declined, life expectancy increased and human societies effectively became 'older', requiring fewer children and having more of the population as adults. This modern demographic transition is summarised in **Figure 6**.

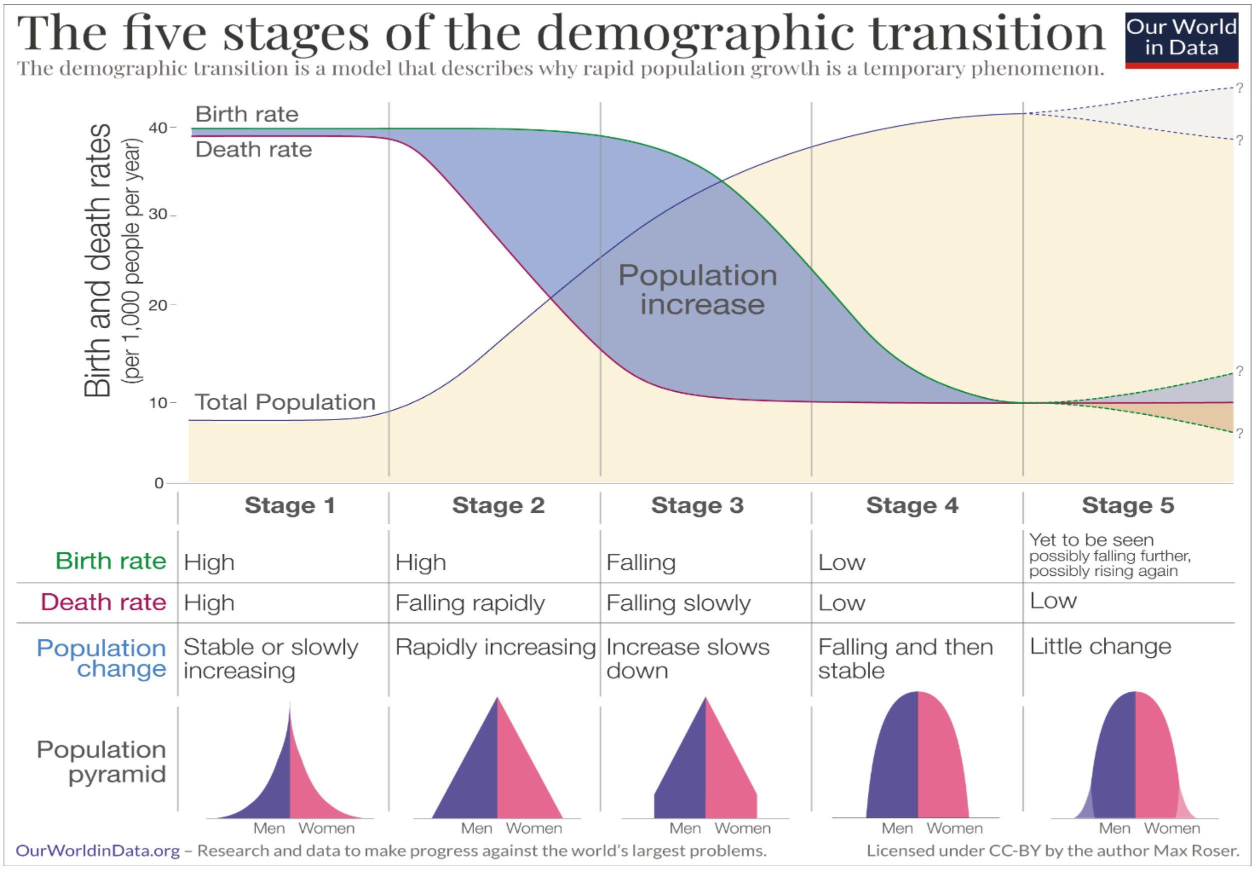


Figure 6*: The modern demographic transition | Source: Roser, 2023*

However, what this illustration omits is the fact that birth and death rates were not equally high across the world in the first stage. As mentioned, they were most likely highest in pathogen-rich tropics and particularly in Sub-Saharan Africa.

Another consideration is future age structure. The demographer Dr Nicholas Nash Eberstadt observes "*a relentless march, all across the world, in child-bearing patterns that will result in below-replacement fertility*" (Eberstadt, 2023). This transition towards sustained low fertility has been termed the *Second Demographic Transition* (Lesthaeghe, 2014). There is still some debate and uncertainty as to when and whether fertility rates will rebound (United Nations, 2022). As of writing however, the empirical data suggests a continued march towards sub-replacement fertility .

Assuming this trajectory holds, the modern demographic transition can be further refined as per **Figure 7**.

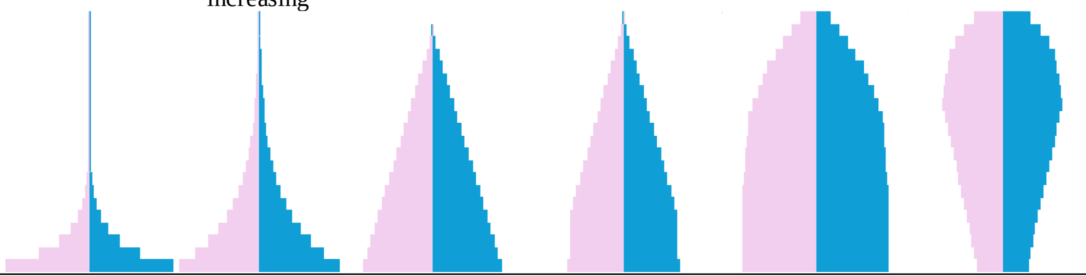
	Stage 0	Stage 1	Stage 2	Stage 3	Stage 4	Stage 5 (sub-replacement)
Birth rate	Highest	High	High	Falling	Low	Lowest
Death rate	Highest	High	Falling rapidly	Falling slowly	Low	Moderate
Likely median age	Mid teens	Late teens	Early 20s	Mid 20s	Late 20s to mid 30s	40s and above
Population change	Stable	Stable and then slowly increasing	Rapidly increasing	Increase slows down	Falling and then stable	Stable and then declining
Population pyramid						

***Figure 7**: The modern demographic transition accounting for severe mortality regimes (Stage 0) and the onset of the second demographic transition (Stage 5)*

Stage 0 represents the age structure under the highest mortality and fertility regime that early homo sapiens experienced, likely in the native environment of Sub Sahara Africa. Stage 1 represents a more forgiving mortality regime which is prevalent in contemporary low-income countries. Stage 5, the "*coffin pyramid*", is the likely age structure emerging as fertility rates continue to trend towards sub-replacement. Stage 5 populations will also experience an uptick in death rates as the elderly population share rises.

Mechanically, the modern demographic transition is triggered once the population's existing population distribution is no longer equivalent to the prevailing survival function. This is illustrated in **Figure 8** comparing Niger's 1990 age structure to the survival function of a developed nation, the United Stated of America.

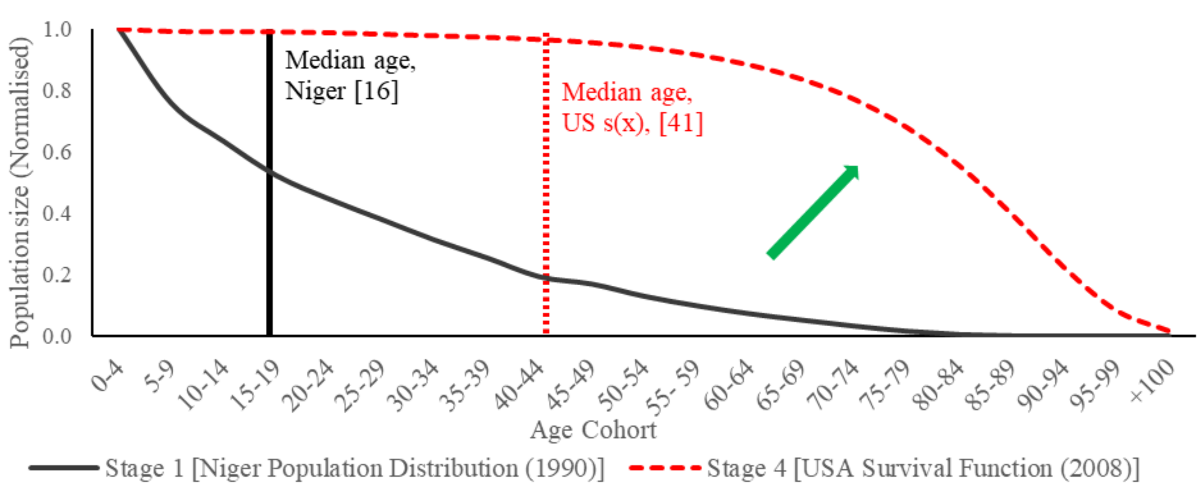


***Figure 8**: An illustration of the complete demographic transition with the median ages. Stage 1 is illustrated by Niger's population. Stage 5 is represented by the USA survival function | Sources: UN, CDC*

The US survival function reflects an age structure that the current population distribution of Niger could *plausibly* achieve assuming convergence in healthcare outcomes, replacement fertility and net zero migration[2]. It can therefore be said that Niger's current age structure is in *disequilibrium* and will, in time, transition to one akin to that of the US.

The speed at which the existing age structure will transition to that of the target survival function can be referred to as the demographic transition rate. This transition rate, and age structure in general, will be determined by the following variables:

1. Birth rate: the lower the birth rate, and all other factors equal, then the faster the transition rate. If the resultant fertility rate declines below replacement however, then age structure will overshoot the equilibrium survival function. This then triggers the Second Demographic Transition.
2. Death rate: the quicker mortality rates decline, specifically infant mortality, then the faster the transition rate. As outlined earlier, geography plays a key role due to varying exogenous pathogenic burden. Another important historic source of mortality has been the introduction of pathogens into human populations through agriculture and animal husbandry (Pearce-Duvet, 2006).
3. Migration: given economic agents typically migrate in their 20s and 30s (Zlotnik, 2012), emigration represents a premature exit from the population. Hence, as with the death rate, this reduces the transition rate, in effect lowering the potential adult population share of the migrant-sending country.

A population distribution by proportion (as opposed to absolute values) is simply the normalised population distribution $p_t(x)$ which sums to 1. Total population of N_t can therefore be expressed as a function of the age structure thusly:

$$N_t = N_t \int_0^{\omega} p_t(x)\, dx \tag{1}$$

The Lee Mason Model

Aggregate production as a function of age and population can now be expressed via the following function:

$$Y_t(x) = N_t \int_0^{\omega} y_t(x) \cdot p_t(x)\, dx \tag{2}$$

As for aggregate expenditure (AE):

$$AE = N_t \int_0^{\omega} c_t(x) \cdot p_t(x)\, dx \tag{3}$$

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[2] The specific choice of the US as a target survival function is solely for illustrative purposes. More broadly, early-stage populations should, over time, expect their mortality functions to converge towards those of developed later-stage economies. Evidence thus far suggests this mortality convergence is on track.

The LM model expresses aggregate production at time t as function of age structure (age and population size). The APF can be normalised by factoring out each age cohort output of $y_{t,x}$ by G_t, the global production maximum; $G_t = max\{y_t(x)\}$. $\check{y}_t(x)$ then represents the normalised APF.

$$Y_t = G_t N_t \int_0^{\omega} \check{y}_t(x) \cdot p_t(x)\, dx \qquad (4)$$

Figure 9 offers a visual illustration of the normalised LM model (essentially, the normalised APF and normalised population distribution).

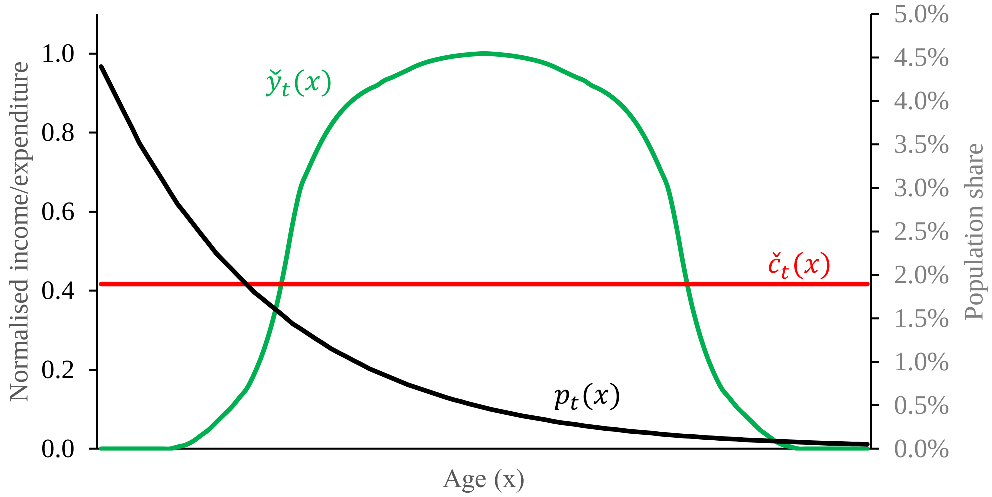


***Figure 9**: The core mechanics of the Lee Mason model - a hypothetical expression of the normalised functions for aggregate production (y), aggregate consumption (c), and population distribution (p)*

The normalised ACF $\check{c}_t(x)$ is included for illustration with G_t as the normalisation factor. An illustrative stage 1 population distribution has been chosen for the normalised population distribution $p_t(x)$.

It is visually clearer now to see how age structure influences the *natural* productivity of the population. The younger and more elderly a population is, then the less productive it becomes on a per capita basis. Per capita production increases the more humans there are closer to the peak production age of x_G.

The LM model can be understood as having two components. First, the *demo-economic aggregates* $G_t N_t$. Population size N_t and the global production maximum G_t are effectively multipliers that describe how much production is achieved given the population's age distribution and normalised APF. The next component is the integral of these population and age production functions and represents the *economic age* of the population.

Demo-Economic Aggregates

Population size is straightforward to interpret: the more people, regardless of age structure, then the more proportionate consumption and production.

The APF global maximum is a normalisation factor that effectively represents the *non-human* inputs of economic production. It can thus be interpreted as a measure of the stock of resources, physical and non-physical, used by humans to achieve economic production. This includes factors such as machinery, livestock, land and infrastructure. A singular coefficient assumes this stock of tools is uniformly distributed across the population.

Economic Age

This normalised expression is a measure of how economically *productive* the human population is distributed with regards to its productive ability across age, as measured by the normalised APF. The normalised APF $\check{y}_t(x)$ captures the natural productivity of the human population and is itself derived from two other functions:

1. Physiological fitness $h(x)$ – economic productivity as a function of the economic agent's physical and mental fitness across age.
2. Time allocation $u(x)$ – effective working hours across age, as determined by social norms and standards around labour participation across age. Unlike physiological fitness, various empirical measurements of this function are available.

$$\check{y}_t(x) = f[h(x), u(x)] \tag{5}$$

By rearranging the LM model equation, the integral is also equivalent to the following quotient where y_t is aggregate income per capita (Y_t/N_t):

$$\psi = \int_0^{\omega} \check{y}_t(x) \cdot p_t(x)\, dx \equiv \frac{y_t}{G_t} \tag{6}$$

This quotient effectively measures the economic productivity of a population solely based on age structure and it is hence termed **Economic Age, $\boldsymbol{\psi}$**.

Due to normalisation, the following properties for this expression emerge:

$$\psi \in (0,1)$$

$$y_t \leq G_t$$

For a given population and stock of tools, economic output per capita (essentially adult production per person) will be maximised when $\psi = 1$. This will occur when the entire population is at the peak production age of x_G achieving output of G_t. In contrast, output per capita would be 0 when $\psi = 0$, which occurs with a population is made up entirely of humans not engaged in net economic production. This understanding allows us to refine the first two Propositions as follows:

Proposition 1: The higher the economic age, the higher the income per capita

The higher the economic age, then the more savings and investment per capita that will be generated, *ceteris paribus*. Assuming this change in economic age persists, the rate of economic growth is then permanently increased. Accordingly, we can refine the second Proposition thusly:

Proposition 2: the higher the economic age, the higher the rate of economic growth.

These Propositions are intuitive. The young and elderly are less economically productive and hence produce less on a per capita basis. And assuming a homeostatic population distribution, a more mature population (higher ψ), will not only produce more per capita but will also save and invest more thus achieving a higher rate of growth and output per capita.

The following sections will better demonstrate the impact of age structure on growth by integrating the LM model principles into the neoclassical framework.

Neoclassical Synthesis

The Cobb-Douglas model posits that each unit of labour (L), uses a mix of capital (K) and technology, or total factor productivity, (A) to produce output (Y). Drawing on this neoclassical framework, we can then include the stock of capital K_t and determinant level of technology A_t as global constants (the economic aggregate G_t) that humans draw on to enhance production.

Using equations (4) and (5), the stock of labour can be expressed as follows:

$$L_t = N_t \int_0^{\omega} h_t(x) \cdot u_t(x) \cdot p_t(x)\, dx = N_t\psi \tag{7}$$

This expression also has obvious parallels with the LM model. The participation function $u_t(x)$ captures the share of working age adults in the labour market and can hence be interpreted as broad participation and employment rate factor. The population density function $p_t(x)$ captures the population age structure. The product is the total stock of human labour in the population factoring in their productivity across age. The traditional neoclassical equations do not account for the variation in worker productivity across working age. This derivation however does and hence advances an arguably more precise estimation of the labour force.

This Cobb-Douglas function can now be derived thusly:

$$Y_t = A_t K_t^{\alpha} (N_t\psi)^{1-\alpha} \tag{8}$$

Given $Y_t'(\psi) > 0$, equation 8 proves Proposition I.

Other core functions within the Neoclassical framework can now be derived.

The per capita savings function is as follows:

$$s_t = A_t K_t^{\alpha} \frac{\psi^{1-\alpha}}{N_t^{\alpha}} - c_t \tag{9}$$

Since $s_t'(\psi) > 0$, the above expression also proves Proposition II.

Where K, κ and r_κ represent the total capital stock, per capita capital stock and capital growth rate respectively, the capital accumulation equations are:

$$K_{t+1} = N_t s_t + K_t(1-\delta) \tag{10}$$

$$\kappa_{t+1} = s_t + k_t(1-\delta) \tag{11}$$

$$\dot{K} = \frac{\partial K}{\partial t} = N_t s_t - \delta K_t \tag{12}$$

$$\dot{\kappa} = \frac{\partial \kappa}{\partial t} = s_t - \delta \kappa_t \tag{13}$$

$$r_\kappa = \frac{s_t}{\kappa_t} - \delta \tag{14}$$

Proposition I is substantiated by the fact that $K'(\psi) = \kappa'(\psi) > 0$. Proposition II is also authenticated by the solution $\dot{K}'(\psi) = \dot{\kappa}'(\psi) = r_\kappa{}'(\psi) > 0$.

The marginal product of capital (MPK):

$$MPK = \frac{\partial Y}{\partial K} = \alpha A K^{\alpha-1}(N\psi)^{1-\alpha} = \alpha \frac{Y}{K} \tag{15}$$

This expression suggests that for any given quantity of capital, the higher the economic age then the greater the effect on output. This is confirmed by the cross derivative with respect to economic age.

$$\frac{\partial MPK}{\partial \psi} = \frac{(1-\alpha)}{\psi^\alpha} > 0 \tag{16}$$

Through the $L = N\psi$ substitution, two hitherto obscured marginal product results can now be derived, namely the marginal products of population and economic age.

Beginning with the *marginal product of population* MPN, the result is as follows:

$$MPN = \frac{\partial Y}{\partial N} = (1-\alpha)AK^\alpha(N\psi)^{-a}\psi = (1-\alpha)\psi(A\kappa)^a \tag{17}$$

Because $\alpha < 1$, $\psi \in (0,1)$ and $\kappa > 0$, MPN is always positive. This is an intuitive result and broadly consistent with the behaviour of the labour factor in the traditional Cobb-Douglas model. However, in this result, the positive relationship with economic age offers further insight. The result helps explains why countries in the initial phase of the demographic transition (Stage 1 to Stage 3) may exhibit anaemic economic growth: the childhood population is surging but economic age remains low and in decline as this initial childhood population blooms. Hence, the positive impact of additional workers on economic output is dampened.

The *marginal product of economic age* MPΨ measures the sensitivity of economic output and productivity to changes in the population's economic age. Given a relatively static normalised

APF[3], this change in age structure is the root cause of the demo-economic transition and exhibits a measurably robust change across time.

$$MP\Psi = \frac{\partial Y}{\partial \psi} = (1-\alpha)AK^{\alpha}(N\psi)^{-\alpha}N = (1-\alpha)N(A\kappa)^{\alpha} \tag{18}$$

Again, MPΨ is always positive and positively correlated with the total population. The latter explains the perceivably sharper uptick in economic expansion as nations transition from Stage 3 to Stage 4 of the transition. Across these stages, both population size and economic age are naturally increasing as the childhood cohorts enter their prime age years.

Both marginal products exhibit diminishing returns to scale as indicated by their second derivatives:

$$\frac{\partial^2 Y}{\partial N^2} = -\frac{\alpha(1-\alpha)AK^2\psi^2}{(N\psi)^{(\alpha+1)}} < 0 \tag{19}$$

$$\frac{\partial^2 Y}{\partial \psi^2} = -\frac{\alpha(1-\alpha)AK^2N^2}{(N\psi)^{(\alpha+1)}} < 0 \tag{20}$$

Regarding economic age, diminishing returns implies that the demographic transition has the greatest positive impact on economic expansion in the middle stages of the transition when the relative increase in working age populations is sharper.

The final insight pertains to the steady-state economy. The steady state output can now be computed on a per capita basis as opposed to the perfunctory per worker iterations. Where r_s represents the savings rate, the steady-state capital per capita and output per capita expressions are:

$$\kappa^* = \psi\left(\frac{r_s}{\delta}\right)^{\frac{1}{1-\alpha}} \tag{21}$$

$$y^* = \psi\left(\frac{r_s}{\delta}\right)^{\frac{\alpha}{1-\alpha}} \tag{22}$$

Once again, the derivations of $\kappa^{*\prime}(\psi) > 0$ and $y^{*\prime}(\psi) > 0$ prove Proposition I. Hence, the conventional convergence hypothesis only holds when economic age is equalised. For as long as material differences in age structure persist, economic convergence cannot be achieved, *ceteris paribus*. The Solowian mechanism is portrayed in **Figure 10**.

[3] There are nuances. Lower income populations tend to have a higher labour participation rate at lower and advanced ages (leptokurtotic APF). NTA data also suggests that their peak production age is earlier. This is most likely a function of how industrialised the population is. So as poor nations develop, their normalised APFs should exhibit lower *kurtosis*. Eventually, APFs should somewhat harmonise.

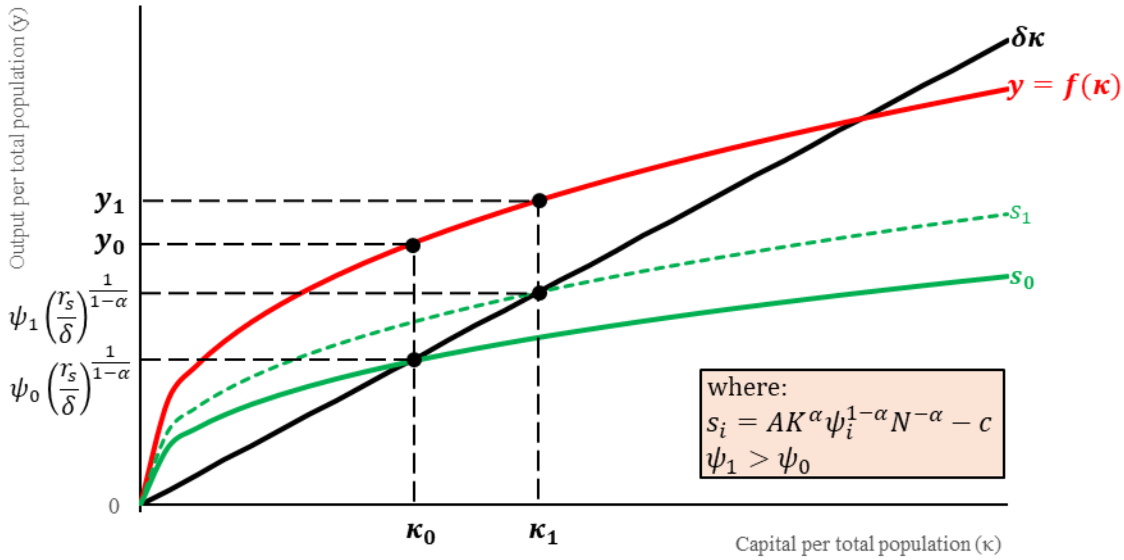


***Figure 10**: The Solowian mechanism of the First Demographic Transition. Even with a static cohort savings rate (r_s), an increase in economic age ($\psi_0 \rightarrow \psi_1$) is economically expansionary and results in a new higher steady-state income ($y_0 \rightarrow y_1$). Effectively, economic convergence is dependent on age structure convergence.*

Endogenous Technological Growth

Endogenous growth theory hypothesises that internal factors determine the rate of economic expansion. This is already broadly consistent with DEG Theory which postulates that workers ($N\psi$) produce ideas (A), goods and services (Y).

Romer introduced the concept of endogenous technological change leading to increasing returns to scale on capital accumulation (Romer, 1986). Later, the concept of non-rivalrous ideas was introduced (Romer, 1990). In summary, Romer's thesis is that the stock of technology (A) is inexhaustible, sourced from the population, and further enhances the productivity of other factors (L, K and A). This section attempts to find an expression for the production and stock of these Romerian ideas across age.

As with the normalised APF for goods and service $\breve{y}_t(x)$, let the normalised APF for Romerian ideas at time t be $\breve{a}_t(x)$. However, unlike the latter, the empirical basis for this Romerian APF is less robust. The NTA datasets serve as estimates for active economic production of general goods and services across age, but it would be imprecise to assume they would be appropriate for the technology function. Nonetheless, credible evidence exists to support the broad principle that production of ideas and innovation is the domain of adults with limited production occurring among those very young or old (Jones, 2010).

Recall Romer's production function for new ideas (Romer, 1990):

$$\dot{A} = \lambda L_A A_{t-1} \tag{23}$$

Technology production is a function of the stock of labour dedicated to generating ideas, denoted as L_t^A, and the opening stock of ideas used to generate these new ideas, A_{t-1}. λ represents the productivity of research.

Recall the labour substitution equation, $L = N\psi$. In this instance, N is still the population size but ψ is the integral of the population density function $p_t(x)$ and the normalised technology APF, $\breve{a}_t(x)$. In this instance the result is as follows:

$$L_{A,t} = N_t \psi_A \tag{24}$$

Where:

$$\psi_A = \int_0^{\omega} \breve{a}_t(x) \cdot p_t(x)\ dx \equiv \frac{a_t}{G_t^A} \tag{25}$$

and $\breve{a}_t(x)$ is the technology production function across age with G_t^A as the respective normalisation constant. ψ_A is hence the economic age *as it pertains to the technology age production function*. This is similar to the earlier economic age function and differs only in that it measures the physiological and sociological aptitude of the human population to generate these Romerian ideas across age. To differentiate it from the economic age related to goods and services production, the subscript A is included. G_t^A represents the technology aggregate – the sttock of idea-enhancing tools. The variable takes on the same numerical properties as derived for equation (6):

$$\psi_A \in (0,1)$$

$$a_t \leq G_t^A$$

Formal proofs of Propositions I and II can be achieved by deriving expressions for $a_t(\psi)$ and $\dot{a}_t(\psi)$ and then solving for $a_t'(\psi) > 0$ and $\dot{a}_t'(\psi) > 0$.

Institutional Economics Integration

A credible case has been made that the quality of economic institutions influences the rate of economic expansion (North, 1991). Some have even gone further and makes the case for institutions as a fundamental cause of long-run growth (Acemoglu, Johnson, & Robinson, 2004). In this section, the principles of DEG Theory are applied to posit that economic age is itself the vital determinant of the quality of economic institutions.

North defines institutions as the formal and informal "*humanly devised constraints that structure political, economic and social interactions*". If humans are incentivised to innovate, save and engage in economic activity for example, then their efforts will spur economic expansion. How humans organise themselves through institutions is therefore, according to Acemoglu et al, interpreted as a key determinant of economic prosperity.

The obvious observation however is that human capital, as captured by economic age, still underpins the effectiveness of these incentivised behaviours. A population of 15-year-old, for example, will certainly not innovate as well as a population of more mature and experienced 30-year-olds. Resultantly, the quality of institutions is a partial function of economic age.

A more demographically mature society should, ceteris paribus, build and maintain more effective political, social and economic institutions. This can be illustrated through the example of what Acemoglu defines as private property institutions, more specifically the rule of law.

The rule of law refers to the set of behavioural norms that aim to ensure all economic agents are treated equally under the prevailing legal system. Rule of law is an essential societal framework that empowers many other useful institutions such as property and human rights (Haggard, MacIntyre, & Tiede, 2008). However, rule of law does not exist as a purely incorporeal *social algorithm*. The mere existence of laws, regardless of their suitability, is insufficient. An effective legal system encompasses various institutional components such as courts, law enforcement agencies, regulatory bodies and the like. Each of these components requires a complement of workers such as lawyers, judges, compliance specialists, legislators, policepersons, clerks and so on. In addition, these workers must be supplemented by tools such as uniforms, computers, buildings and vehicles. In other words, these institutions still require a functional stock of human and physical capital to adequately dispense their services such that rule of law is effectively administered. Moreover, this stock of human and physical capital needs to be commensurate with the size of the population, and to a lesser degree, the geography. High quality institutions are those that not only have the right ruleset (codes, laws, processes, procedures – effectively the *social algorithm*), but also the right quantity of human and physical capital to develop, execute and maintain the algorithm. The ratio of workers to the total population (effectively the economic age) is therefore a key variable influencing the quality of these institutions.

At a low economic age, societies may simply not have the right quantity of skilled personnel and complementary capital per total population. With fewer court judges per capita for example, a society will find it harder to dispense rulings in a timely and judicious manner thus weakening the rule of law.

It is possible for such younger societies to divert adult workers towards certain institutions to make up for the lower worker-to-population ratio. However, this is a suboptimal solution because the production of other key goods and services such as food, healthcare and education may now be compromised.

In summary, institutions are themselves greatly influenced by economic age. The higher the economic age, *ceteris paribus*, the greater the human capacity and hence quality of institutions.

Human Agency versus Demography

An argument can be made that age functions as a *biological* driver of human agency. Agency, in the context of the social sciences, includes a range of competencies that enable economic agents to maximise their long-term utility[4]. Within this context, Bandura's Social Cognitive Theory (SCT) offers a rigorous and well-reviewed definition of human agency (Bandura, 1989) (Bandura, 2006). SCT outlines four core capabilities of human agency: intentionality, forethought, self-reactiveness and self-reflectiveness. And all four components are functions of what Bandura terms

[4] This definition differs from the more philosophical variant of free will or moral agency. Within the context of the economic sciences, the focus extends beyond just free will and focuses on the *capacity* to decide and act in a manner that better maximises utility.

"*patterns of neural activities characterizing interpretive and deliberative thought processes*". Human agency is therefore, to an extent, a function of neurocognitive aptitude, which itself is greatly influenced by age, among other factors.

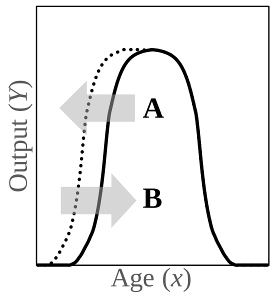
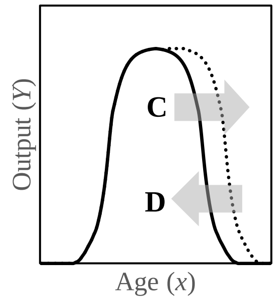
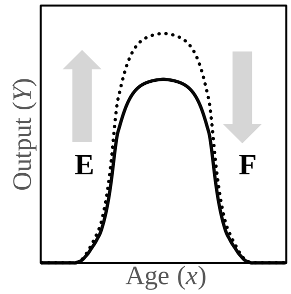
The result is intuitive. Colloquially, human agency is *the ability to get things done*. And adults, with their superior cognitive and physical aptitude, are more suited to this task. Another advantage older humans possess, which increases with age, is experience. As Bandura notes, "*humans require a prolonged period of development to master essential competencies*".

In summary, human agency is a partial function of age structure. The higher the economic age, then the more human agency that population is endowed with. Even if one posits that human agency, and its assorted derivatives such as culture and behaviour, is the fundamental determinant of socioeconomic progress (Altman, 2001) (Ferguson, 2012), any such socioeconomic model is again, bounded by economic age.

Consolidated Framework

Returning to the Lee Mason model, a more granular framework of age structure and its macroeconomic impact can now be derived. This will be achieved through geometric representation as opposed to algebraic computation given the APF is, at its core, a stochastic differential equation. In addition, a visual illustration is arguably easier to understand conceptually, as is the case with elementary indifference preference functions (demand and supply curves).

The schedule below shows the various possible shifts of the APF by segment together with the effect on the demographic transition rate ($\partial\psi/\partial t$), likely cause (sociological, physiological or economic) and macroeconomic effect (output and growth per capita).

APF segment	Left tail	Right tail	Amplitude
APF curve change $\frac{\partial y(x)}{\partial t}$	 ***Figure 11**: Left tail expansion (A) and contraction (B)*	 ***Figure 12**: Right tail expansion (C) and contraction (D)*	 ***Figure 13**: Expansionary (E) and contractionary (F) shift*
APF effect	Increase (A) or decrease (B) in output at younger ages.	Increase (C) or decrease (D) in output at older ages.	Increase (E) or decrease (F) in labour productivity
$\frac{\partial \psi}{\partial t}$	>0 if increase (A) <0 if decrease (B)	>0 if increase (C) <0 if decrease (D)	>0 if increase (E) <0 if decrease (F)
Causal channel	Sociological factors – changes in labour participation rates $u(x)$	Sociological and physiological factors $h(x)$	Sociological and physiological factors. Also, economic aggregate $G\ (AK)$
Economic effects	Increased economic output & growth rate (A, C & E) Decreased economic output & growth rate (B, D & F)		

Regarding the right tail APF shift (C), a modern example are the recent improvements in healthcare and exposure to risk factors spurring healthy life expectancy (Mathers, Stevens, Boerma, White, & Tobias, 2015). For the APF to truly shift however, this improved physiological fitness would need to be complemented by increased labour participation rates.

Regarding changes in the APF's amplitude (E and F), sociological and physiological factors would likely have a limited impact. The main factors influencing the APF's amplitude would be the economic aggregates of technology and capital as indicated by the result derived in equation (4). Capital deepening would shift the APF upwards while capital shallowing would lead to the reverse.

Economic effects may also influence other factors such that the impact on the economy is changed (bi-causal and feedback effects). For example, an upward shift in the APF could be realised by increasing working hours. But as will be highlighted in the next chapter, that may come with costs to physiological health such that the initial APF increase is at least partially reversed.

Lastly, consideration must also be given to non-uniform idiosyncratic shifts in the APF. These represent changes in the shape or amplitude (or both) of the APF that don't clearly align with the more consistent motions described above. For example, a military conflict might see potential young workers divert their time to military service instead of economic production. This might also impair productivity due to labour constraints, infrastructure losses and compromised institutions. This may then induce a localised reduction in the APF amplitude at earlier ages as labour participation and lifetime income declines due to the abovementioned productivity impairments. This is illustrated in **Figure 14**.

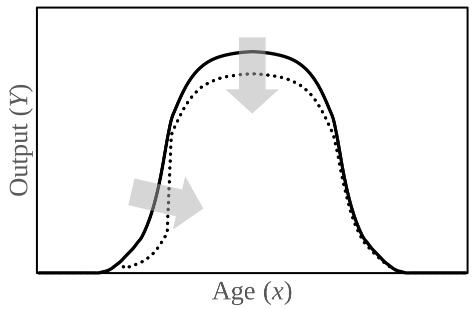
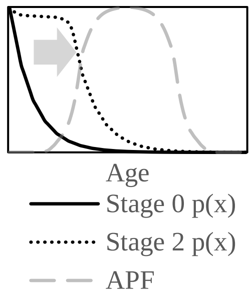
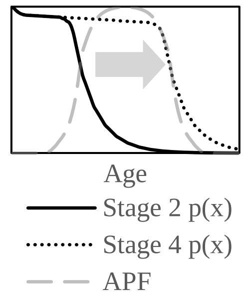
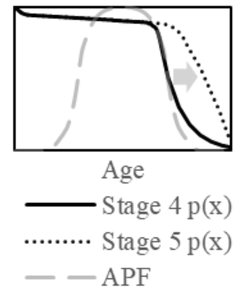


***Figure 14**: Idiosyncratic APF shift*

Regarding shifts in the age structure, these are best illustrated through the demographic transition. As mentioned earlier, the demographic transition is in essence triggered by a change in the human mortality regime $\mu(x)$ such that the existing age structure at time t, $p_t(x)$, transitions to that of the target survival function as dictated by the new mortality regime. This was illustrated earlier in **Figure 8**.

Below is the illustration of the various transition age structures and the effects on the economy arising from the demographic transition, assuming an immediate change in the mortality function. This also assumes a transition to replacement fertility with net zero migration across all cohorts (demographic equilibrium). The demographic *transition phase* refers to the transitions between the demographic *stages*. The precise stage is more of an estimate; what is more important is the impact on economic age across the transition.

Transition Phase	Malthusian Epoch	First Demographic Transition	
Transition Stages	Stage 0 to Stage 2	Stage 2 to Stage 4	Stage 4 to Stage 5 (equilibrium)
Age structure change	 ***Figure 15**: A Stage 0 to Stage 2 demographic transition*	 ***Figure 16**: A Stage 2 to Stage 4 demographic transition*	 ***Figure 17**: A Stage 4 to Stage 5 demographic transition*
Age structure effect	Increasing share of humans in the Development Phase	Increasing share of humans in the Production Phase	Increasing, then stabilising share of humans in the Senescence Phase
Causal channel	Lower infant mortality releases a pre-transition infant cohort into pre-adolescence (Lam & Marteleto, 2008)	The pre-transition infant cohort transitions into adulthood (assuming limited brain drain).	The pre-transition infant cohort (now adults) transition into the Senescence Phase.
Economic Age	Declining, $\frac{\partial \psi}{\partial t} < 0$	Increasing, $\frac{\partial \psi}{\partial t} > 0$	Declining $\frac{\partial \psi}{\partial t} < 0$ then stabilising $= 0$ when in demographic equilibrium
Economic impact	Declining economic age dampens the economic growth rate. This may be ameliorated by higher marginal product of capital	Increasing economic age propels economic growth. The effect is stronger in the earlier stages given diminishing returns of ψ	Economic age declines slightly and approaches equilibrium. Economic growth rate moderates and reaches equilibrium at replacement fertility.

In what Oded Galor's Unified Growth Theory terms the Malthusian Epoch, population growth outpaces or matches economic growth (Galor, 2011). This initial phase's economic drag offers a partial explanation as to why post-Colonial Africa failed to live up to the expectations of rapid economic expansion. The end of colonialism ushered an expansion of healthcare services to the previously neglected local populace (Turshen, 1977). In the case of Africa, this expanding pre-transition infant cohort was protracted given the more acute exogenous pathological burden.

The First Demographic Transition (Stage 2 to Stage 4) illustrates why the demographic transition infuses a permanent stimulus to economic growth. Economic age does not decline to that of earlier stages even as the elderly cohort expands. A population that completes the transition to stage 4 or

5 will, ceteris paribus, persistently expand faster than an early-stage population. Another key implicit assumption here is constant returns to scale with regards to capital per worker. But even with this assumption relaxed, an economic divergence would likely persist, ceteris paribus.

The final equilibrium transition remains elusive empirically. Most economies seem to be graduating rapidly towards the Second Demographic Transition instead.

Figure 18 consolidates the LM model thesis and demonstrates the process of this demo-economic transition. Additionally, this better explicates the causal mechanism of the first two Propositions.

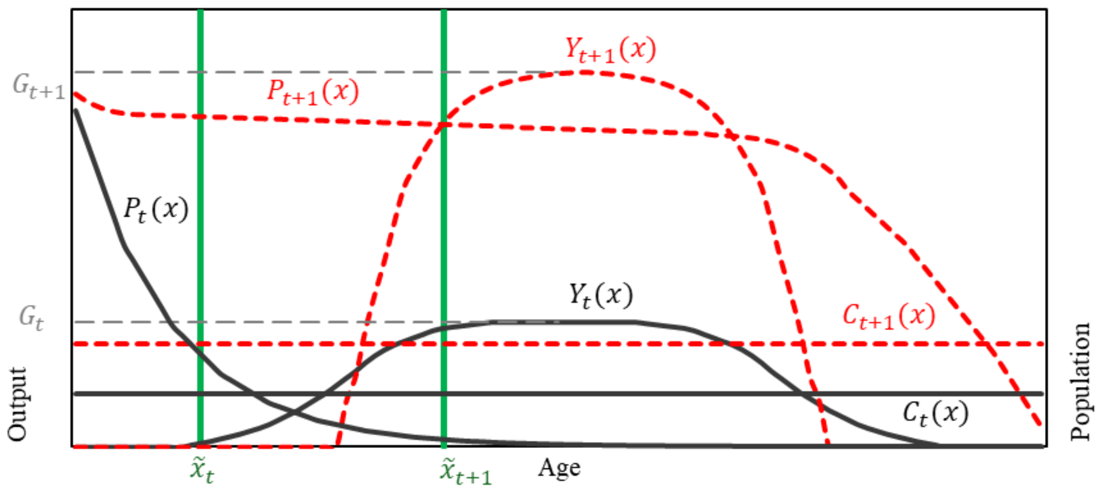


***Figure 18**: Illustration of the demo-economic transition. The first demographic transition matures the population (shift in age structure P(x) and increase in median age, $\tilde{x}$). This then increases the aggregate equilibrium savings rate thus propelling capital and technology (G), productivity (Y) and consumption (C).*

Young and unproductive societies were the norm for much of human history. This configuration is represented by the Stage 0 population distribution with a median age of $\tilde{x}_t$ and the lower-amplitude APF and ACF, $Y_t(x)$ and $C_t(x)$ respectively. As illustrated, there was a population and age productivity mismatch with much of the human population persisting at less productive young ages. Resultantly, the stock of knowledge and capital as represented by G_t was low. Due to the *stickiness* of autonomous consumption, economic surplus of $N_t \int_o^\omega P_t(x) \cdot [Y_t(x) - C_t(x)]dx$ was likely modest resulting in a negligible steady-state capital per worker and growth rate.

The First Demographic Transition, as initiated by a moderation in the mortality function $\mu(x)$, induces a progression in the *natural* economic productivity of the underlying population. This mortality moderation is a function of both exogenous forces such as pathogenic richness and endogenous factors such as healthcare services. The enhanced natural economic productivity is realised through the physiological and sociological *maturation* of the human population as a larger share of the population persists at more productive ages. The economic surplus is enhanced and the resultant increase in per capita human agency, capital and productivity amplifies the APF over time. This results in a higher APF, ACF and median age of $Y_{t+1}(x)$, $C_{t+1}(x)$ and $\tilde{x}_{t+1}$ respectively.

A demographic equilibrium is attained once the population structure $P(x)$ is in equilibrium (replacement fertility and net zero cohort migration) at the Stage 5 (equilibrium) population distribution. Recall that under the neoclassical synthesis, the growth rate of capital in continuous time, where c represents consumption per capita, is as follows:

$$g_\kappa = \frac{\partial \kappa}{\partial t} = (AK\psi/c)(1-\delta)$$

And recall that the stock of capital and technology (AK) is represented by the global maximum of the APF G_t. Post-transition, the population is endowed with a higher economic age ψ, stock of capital and technology and lower aggregate marginal propensity to consume. Thus, as per the Proposition II, the economy expands faster.

NTA data also suggests that in more developed Stage 5 economies, fewer years are spent in the workforce as the young spend more time in education and the old can retire earlier thanks to increased lifetime earnings. This is illustrated by the narrower base of the APF at time $t+1$.

In summary, the demo-economic transition represents a symbiotic positive feedback mechanism between demographic and economic forces. However, demography is the causal factor. Demographic maturation is what endows the underlying population with the competence necessary to develop, effect and benefit from growth-inducing economic policies. Even when economies fail to implement the right economic policies, completing the demographic transition and sustaining a superior economic age preserves the possibility for future policy corrections and subsequent economic prosperity. The contraposition however does not hold – in the absence of demographic maturity, the empirical evidence strongly indicates that economic progress remains elusive.

General Method

For any given economic model, heterodox or otherwise, derivation of the empirical age regressors and proof of the first two Propositions can be achieved through the following 3-step operation:

Step 1 – Derive:	**Step 2** – Solve for regressors and proofs:	**Step 3** – Repeat for all model predictor variables	*Proposition proof*
$y(\psi)$	$\frac{\partial y}{\partial \psi} > 0$	Applies to all factors that are at least partially a function of human labour and utilises the respective economic age variant.	*I*
	$\frac{\partial^2 y}{\partial t\, \partial \psi} > 0$		*II*

For the Solow model with human capital, where $H = Nh$, the operation would be as follows:

Step 1 – Derive:	**Step 2** – Solve for regressors and proofs:	Proof of:
$\boldsymbol{y}(\boldsymbol{\psi})$	$\boldsymbol{y}'(\boldsymbol{\psi})$	*Proposition I*
$a(\psi_A)$	$a'(\psi_A)$	
$\kappa(\psi_K)$	$\kappa'(\psi_K)$	
$h(\psi_H)$	$h'(\psi_H)$	
$\dot{\boldsymbol{y}}(\boldsymbol{\psi})$	$\dot{\boldsymbol{y}}'(\boldsymbol{\psi})$	*Proposition II*
$\dot{a}(\psi_A)$	$\dot{a}'(\psi_A)$	
$\dot{\kappa}(\psi_K)$	$\dot{\kappa}'(\psi_K)$	
$\dot{h}(\psi_H)$	$\dot{h}'(\psi_H)$	

Chapter III: Economic Age

Omnia tempus habent

$$\psi = \int_0^{\omega} h(x) \cdot u(x) \cdot p(x)\, dx$$

This Chapter, split into three sections, is dedicated to further exploring these three key components of economic age: physiological fitness $h(x)$, labour time allocation $u(x)$ and population distribution $p(x)$.

In doing so, several variants (decomposition effects) of economic age can be derived. These variants are useful for analysing and quantifying the effects of an assorted range of social, demographic and physiological factors.

Time Allocation

Time allocation methods within the social sciences are well-established and is an indispensable tool for understanding human behaviour (Gross, 1984). Time has also been well instantiated as an economic resource (Becker, 1965). Unlike economic output, as measured by the inherent vagaries of imperfect human markets, time is a fundamental property of the universe and hence offers a more axiomatic cost basis for estimating economic activity.

All economic production is a function of labour time. Regardless of the factors of production in terms of quality and composition, labour time is necessary to achieve output. Even with automation, labour time is still required to design, build and maintain the automated process. The stock of labour time is therefore a fundamental economic resource (Klein, 2007). On a per capita basis, labour time can hence be interpreted as function of age structure – the higher the share of adults in the economy, then the more labour time per capita.

Using the same methodology for economic age, a construct for labour time allocation across age, what has been termed the **Economic Age of Time**, can be constructed as follows:

$$\psi_\tau = \int_0^{\omega} u_t(x) \cdot p_t(x)\, dx \qquad (26)$$

If $\psi_T = 0.5$ then approximately the equivalent of half the human population is engaged in economic production at any given time. So, the economic age of time measures the available hours of nominal economic production available per capita. An important caveat to note here is that this just covers human production time per capita. Economic agents also consume the production of non-human production time such as machine and animal hours. These non-human work hours are simply the economic aggregates AK (or G in the LM model), which are themselves a function of the underlying age structure.

There are obvious limits to how high temporal age (basically work time) can go. Economic agents obviously need time for other activities essential for their existence and wellbeing. Activities such as child-rearing, leisure and sleep are all just as essential, to an extent, as time spent producing economic goods and services. Hence, balance is required. But balance is not just required on work time allotted across age, its’s also required on work time allocated across multiple other dimensions.

The following three case studies highlight the importance of time optimisation across many contexts.

Case Study I: Workism Paradox

A contemporary example of possible suboptimal time allocation would be the ongoing decline in fertility as *partially* influenced by the rise of work-focused values (DeRose & Stone, 2021). This cultural disposition, termed “workism” by the authors, drives individuals to assign increasing importance to work as a source of value and meaning at the expense of family formation. In effect, households are allocating more time towards economic production at the expense of family formation and future labour production. In effect, a paradox ensues whereby increased allocation towards current economic production may eventually induce a decline in future per capita production time, and hence economic prosperity, as fewer workers enter the labour force due to declining fertility and an ageing elderly population.

Case Study II: Pre-Industrial Economic Stagnation

Due to persistently high infant mortality, pre-industrial human societies had high replacement fertility rates and hence low economic ages. This demographic configuration meant a lower ratio of adults to the general population. Resultantly, the economic age of time was likely low, plausibly leading to a level of production that was almost exclusively devoted to meeting autonomous consumption. If so, time dedicated to technological innovation would have been scarce thus leading to persistently low and stagnant economic growth.

This argument again supports various Propositions and would partially explain why it was older societies at higher latitudes and altitudes, with lower pathogenic burdens, that gained the advantage economically throughout various periods of history.

Other corroborating explanations have been offered for this positive correlation between latitude and economic development rates. Gallup and Sachs rightly identify pathogenic burden as estimated by the endemicity of malaria (Gallup & Sachs, 1999). However, they don’t rigorously extend this factor to age structure and the effect on the economy. Other bodies of literature cite economic institutions as the causal factor. This perspective has been discussed earlier in this paper.

The vital learning from this case study is that age structure has plausibly impacted labour time per capita thus materially influencing economic development across history. There are lessons for older societies currently entering the Second Demographic Transition. These societies may benefit from paying more attention to the possibility that ageing populations, with declining working age cohorts, could usher in a new era of economic stagnation as labour time per capita once again retreats. Evidence of this potential demography-induced “economic winter” is emerging (Lee, Mason, & Park, 2011) (Maestas, Mullen, & Powell, 2023) (Kotschy & Bloom, 2023). This trend in declining economic age also somewhat supplements the demographic secular stagnation hypothesis (Cervellati, Sunde, & Zimmerman, 2017).

Case Study III: Time Poverty

Time poverty emerges when humans are compelled to allocate much of their available time towards labour such that they have insufficient time for other essential activities. This is akin to the *workism paradox* except in this instance, there is a lack of agency on the part of the worker. An example of time poverty in developed economies could be economic agents having to work multiple jobs to afford basic costs such as rent, food and heating such that they have insufficient time to eat healthy and exercise, consequently leading to adverse health outcomes (Kalenkoski & Hamrick, 2013). Another example of *time poverty* could be subsistence rural farmers having to spend much of the year using basic tools to extract minimal nutrition from the land instead of learning new skills and engaging in more productive specialised work through the division of labour. In this example, there is a shortage of discretionary time which could be used to enhance production from a subsistence to specialised level.

Time poverty has similarities to the pre-industrial economic stagnation because in both instances, agents are essentially compelled to allocate a preponderance of their available time to meeting just autonomous consumption. Time poverty however is not a consequence of demography but rather economic and social forces. Regarding potential policy solutions, a subsistence farmer could be unfettered from their *time poverty trap* through the reliable provision of healthy prepared meals thus allowing the farmer to eventually channel their labour time towards more productive specialised labour. Soviet factory kitchens for example, arguably served such a purpose (Afonina, 2022). Such a policy could also ameliorate the aforementioned health effects of time poverty in developed countries. More generally, the regular provision of such nutrition could effectively increase aggregate discretionary time as households spend less time shopping and preparing food themselves.

A Time for Everything

Time is a fundamental resource consumed equally and consistently by all humans for a range of activities necessary for the sustenance of themselves and their broader ecosystems. These case studies illustrate how time allocation can have profound effects on human economic and social wellbeing. Optimal time allocation can be distorted by factors such as work life balance (workism), economic incentives (time poverty) and demographic forces (age structure).

Physiological Fitness

Physiological fitness is primarily a function of one’s mental and physical health. These are in turn influenced by a range of factors such as diet, genetics[5] and healthcare access. There exists a positive relationship between healthcare outcomes and economic prosperity (Bhargava, Jamison, Lau, & Christopher, 2001) (Weil, 2014). However, the precise nature of these factors and the full causal mechanism with regards to economic productivity encompasses a literature base well outside this paper’s scope.

[5] It ideally need not be said, but sadly it does: the author assumes no differences in economic aptitude due to immutable characteristics such as ethnicity, “race”, gender, sex, sexuality and so on.

Hence, a simplifying assumption is made. Let $\lambda \in (0,1)$ be the dampening effect that explains the deviation from a *nominally* peak-health human population. This variable then represents the range of deficits in human physiological health from a nominal *beau idéal* control population. The exact statistical definition of this control population would be discretionary. A curated subpopulation for example. The population could also be theoretical in nature, being the product of a range of healthcare target outcomes, perhaps associated with a target economy.

λ now represents various physiological deficits, as captured by healthcare outcomes. Plausible factors for inclusion in this variable include malnutrition (Siddiqui, Salam, Lassi, & Das, 2020), disability (Quieros, Wehby, & Halpern, 2015) and environmental exposures (Riva, Lafranconi, D'orso, & Cesana, 2012), among others.

Population Decomposition Analysis – A Demonstration

Adults may be the ultimate source of labour but not all adults are equally endowed in terms of productive capacity. Economic production will come from a segment of the adult population that is better educated, employed, healthy and so on. Identifying and measuring which precise segments of the adult population generate economic output is not the point of this section. Rather, what follows instead is a short technical demonstration of how one could decompose the population structure in order to evaluate said segments.

Let the total population be split by the following criteria:

- Rural (R) or urban (B)
- Skilled (S) or unskilled (U); those with say, over 10 years of formal schooling, or the equivalent thereof would be skilled

Subsequently, there will be four population groups:

1. Skilled rural population - p_{SR}
2. Skilled urban population - p_{SB}
3. Unskilled rural population - p_{UR}
4. Unskilled urban population - p_{UB}

Given these discrete categories, economic age is as follows:

$$\psi = \sum_{j=1}^{n} \left[(1 - \lambda_j) \sum_{x=1}^{\omega} \left(u_{x,j} \cdot p_{x,j} \right) \right]$$

In this expression, there are n=4 population categories such that $\sum_{j=1}^{n} p_{x,j} = p_x$. Economic age can then be distilled into the following subcomponents:

Definition	Name	Description
$(1-\lambda_{SR})\sum_{x=1}^{\omega}(u_{x,SR}\cdot p_{x,SR})$	Skilled rural economic age	Age structure as it pertains to economic production among the skilled rural population
$(1-\lambda_{SB})\sum_{x=1}^{\omega}(u_{x,SB}\cdot p_{x,SB})$	Skilled urban economic age	As above but for the skilled urban population
$(1-\lambda_{UR})\sum_{x=1}^{\omega}(u_{x,UR}\cdot p_{x,UR})$	Unskilled rural economic age	As above but for the unskilled urban population
$(1-\lambda_{UB})\sum_{x=1}^{\omega}(u_{x,UB}\cdot p_{x,UB})$	Unskilled urban economic age	As above but for skilled urban population

The objective of this decomposition approach is to expose and analyse the effects of specific subpopulations on economic age and overall economic performance. In this sample decomposition for example, the skilled urban population would arguably be a stronger driver of economic activity. This is because urban and skilled populations tend to be materially more productive than unskilled and rural populations (Shaban, Kourtit, & Nijkamp, 2022) (Gennaioli, La Porta, Lopez-de-Silanes, & Shleifer, 2013).

Other factors can also be included for this analysis. Class, work-from-home policies, migration and other such factors can all be incorporated to better understand the nature of economic age and how it interacts with economic performance.

Finally, it is important to note how various aspects of these components are related to other aggregates in the broader model. Public infrastructure for example reasonably has a positive relationship with the urbanisation rate. The share of skilled workers will likely also be positively correlated with investments in education.

Chapter IV: Empirical Analysis

Nihil autem opertum est, quod non reveletur, neque absconditum, quod non sciatur

Empirical Review

The existing empirical literature on the correlation between age structure and economic growth is extensive and strongly consistent with the Propositions presented in this paper. Various authors, using a range of methodologies, find a positive correlation between economic age (or rather the estimators of economic age) and the level and rate of economic development. Using the ratio of the working age population to the general population as an estimator, this positive correlation holds globally (Bloom, Canning, & Sevilla, 2003). Incorporation of age structure has also been demonstrated to improve economic forecasts in some models (Bloom, Canning, Gunther, & Finlay, 2007) (Doppelhofer, Miller, & Sala-I-Martin, 2004). Empirical evidence of APF downward concavity, such as Chong-Bum's Demographic U Hypothesis (Chong-Bum & Seung-Hoon, 2006), is also found in studies exploring the impact of cohort structure on economic growth (Hyun-Hoon & Kwanho, 2019) (Zhang, Zhang, & Zhang, 2015).

A rich body of work attributes much of East Asia's recent economic expansion to its rapid demographic transition (Radelet, Sachs, & Lee, 1997) (Bloom & Williamson, 1998) (Bloom & Finlay, 2009) (Pei-Ju, 2011). Within Asia, "*China's rapid economic growth has been significantly attributable to changes in demographic structure*" (Zheng & Rui, 2010). Other regions where the demographic transition has been documented to drive growth include the MENA (Forouheshfar, El Mekkaoui, & d'Albis, 2020) region. This positive correlation is further preserved at a sub-national level (Crombach & Smits, 2022) using the dependency ratio as an economic age estimator.

In summary, a strong and persistent positive correlation between economic growth and economic age is empirically substantiated at a global, regional and sub-national level. The purpose of this chapter is to offer a macroeconomic substantiation of the APF using median age as the estimator. This offers a much simpler framework for assessing macroeconomic performance vis-à-vis age while still highlighting the stochasticity, non-monotonicity and non-linearity of the relationship. Finally, a critique is provided on the prevailing work horse of demographic economics, the Demographic Dividend Hypothesis (DDH).

Methodology and Results

Given the stochastic nature of the APF and demographic transition itself, a simple stochastic process has been developed using median age $\tilde{x}$ as the independent variable (and hence the economic age estimator) and real GDP per capita as the dependent variable.

$$y_t(\tilde{x}): t \in T$$

Just as the NTA framework measures economic output across an agent's lifecycle, this model gauges macroeconomic productivity as a function of a population's own demographic lifecycle, the demographic transition, as estimated by median age.

Axiomatically, this model introduces an omitted variable bias. In this case, that variable is the economic aggregate G, which can in turn be dissolved into its various constituent parts such as human capital, TFP, capital and so on. The causal economic channels are as follows:

- Per Proposition I, the higher the median age, up to a certain point, the higher per capita effective adult production time and hence economic output, *cet. par*. Throughout this transition, improvements in human capital fortify the economic expansion. Two causal forces are at play: more adults per capita induces more workers per capita (to a degree) and more education from these workers means even more skilled adults per capita hence more skilled workers per capita. However, further increases in median age induce less significant changes in productivity and eventually decrease economic age, slowing economic expansion and possibly lowering per capita output at the extremes.
- Per Proposition II, a higher median age induces a higher rate of economic growth *cet. par*. As before, this applies only up to a certain point.

In both cases, the decline in per capita output and growth emanating from the Second Demographic Transition will be dampened by the accumulated economic aggregates. Put differently, ageing societies can better rely on accumulated technology and capital to stave off the effects of low and declining economic age. Effectively, the function should be asymmetrical with per capita output stagnating and then declining more slowly as median age advances.

Real GDP per capita is sourced from the Penn World Table 8.1 (Feenstra, Inklaar, & Timmer, 2015) while median age is obtained from the UN (United Nations, 2022). Using five-year gaps, a period from 1950 to 2015 was chosen encompassing 182 countries with almost 2000 observations.

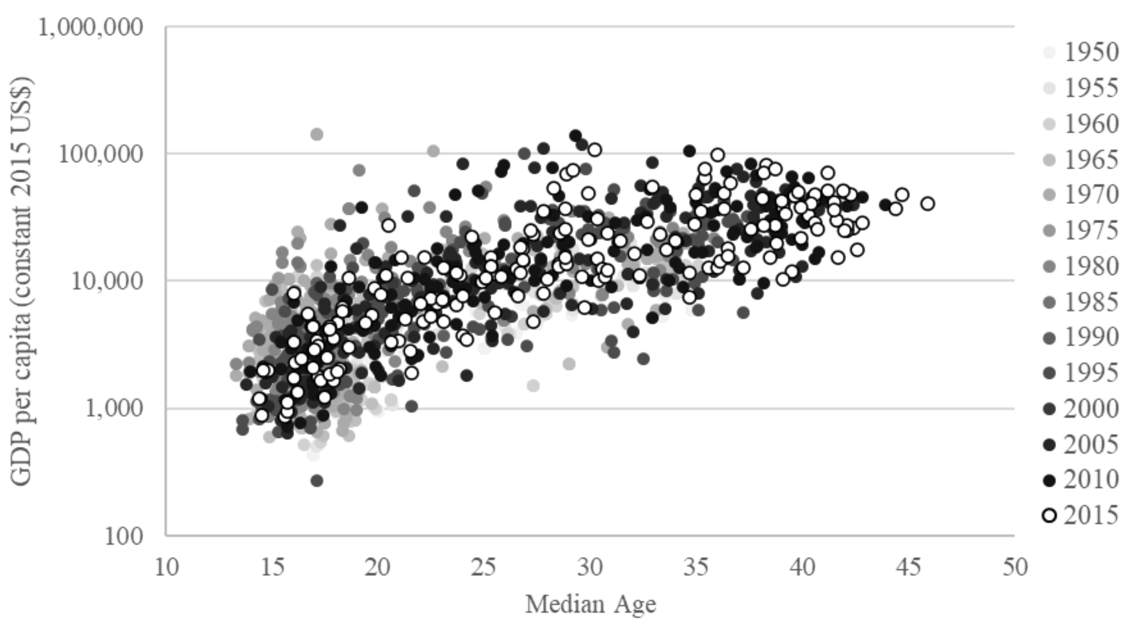


Figure 19*: Stochastic process of national per capita income (y-axis) across time (light to dark, then bordered markers) and across median age (x-axis). This model covers 180 countries over 65 years | Sources: UN, Feenstra et al.*

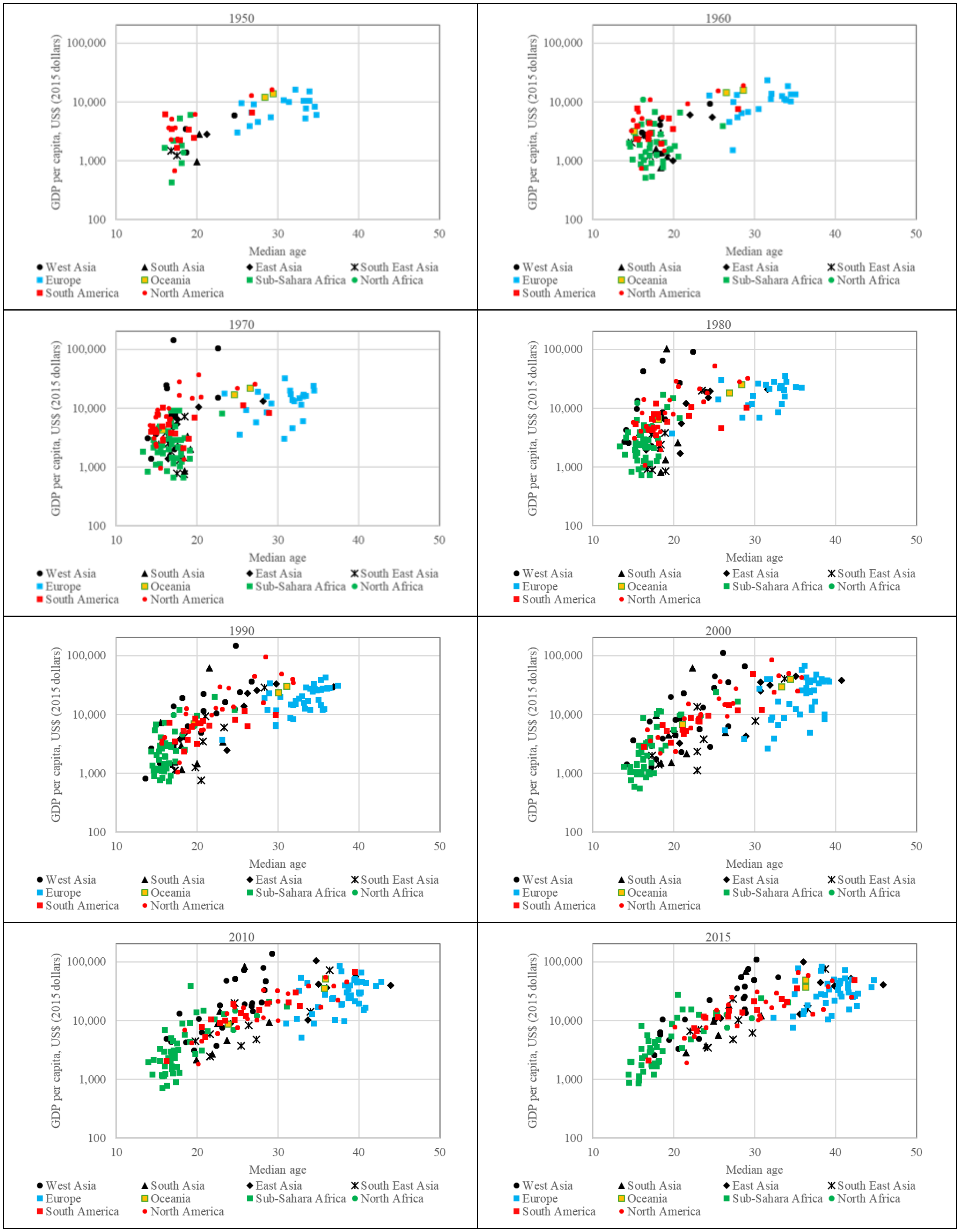
The results in **Figure 19** confirm this widely validated positive and causal relationship between economic age and productivity. Even with the omitted variable bias, the correlation is clear. This is because the economic aggregates are themselves partial functions of age structure. The following statistical properties can be deduced:

1. **Concavity**: a non-linear concave (downwards) function persists as per the underlying individual NTA framework. As the trend shows, almost no economy has sustained meaningful prosperity without transitioning – no pre-transition developed countries. Equally, every economy that has ever transitioned also experienced a material uplift in productivity – no post-transition least developed countries. Nobody misses the demographic dividend, and nobody gets rich without a demographic transition. This supports Proposition III of the demographic transition functioning as an economic transition.
2. **Asymmetry**: concavity is stronger at younger age ranges. This is consistent with the result derived in equation (20): the expansionary effects of rising economic age are stronger in the earlier phases. This greater sensitivity of economic productivity to age at earlier demographic stages also supports Proposition IV given the preponderance of young age structures throughout history[6].
3. **Persistence**: this concave relationship is preserved longitudinally even in early periods from 1950 to 1990 when the data was arguably less reliable, especially for developing countries. This is possibly the strongest empirical indicator of causality.
4. **Heteroscedasticity**: the heterogenous variance of income at latter ages is expected due to the inherent variation in growth trajectories as influenced by other factors such policy, institutions, resource endowment, trade and so forth. In contrast, when countries are young, variation in prosperity is limited. This is a result deduced in equations (9) and (13): when populations are very young, a Malthusian trap of sorts occurs as a higher aggregate marginal propensity to consume limits savings accumulation. Moreover, investment itself might barely cover the capital depreciation. Lastly, economies that transitioned earlier, such as those in Western Europe, had more time to accumulate their economic aggregates. Consequently, such economies will generate higher per capita productivity than similarly aged economies that transitioned more recently.

Table 1 offers a regional and directional analysis of this stochastic process.

[6] Pre-historic APFs were obviously different to modern ones. The prevalence of child labour likely skewed the APF towards younger age groups. However, given the lower physiological fitness of younger cohorts, it is reasonable to expect that such young populations retained greater economic sensitivity to changes in age structure.

Table 1*: Stochastic process of economic productivity as a function of median age across time*



What follows is a commentary on these demo-economic trends across select regions, highlighting how the speed and timing of the demographic transition has affected economic development and variation.

West Asia: Encompassing the Middle East and Central Asia, this region is broadly in Stage 3 of the transition and has resultantly registered a material uplift in living standards. Many of these populations have at times also exhibited the anomalous result of high per capita output at earlier transition stages. For example, Bahrain and Oman were able to register very high levels of real per capita output in the 1970s while still in the initial phases of the transition due to factors such as the 1973 oil crisis. This anomaly is also the result of having a high mineral resource endowment (crude oil) relative to the population. These anomalies have moderated more recently and accounting for such outliers does suggest that the *path* of the underlying demo-economic transition is narrower.

South Asia: In Stage 3 of the transition, countries such as India are already at sub-replacement fertility and are thus progressing towards the Second Demographic Transition. Partially spurred by this decline in fertility rates, these regions are also registering robust growth, for now. However, India specifically is still behind its global peer group, as measured by median age, and can hence deemed to be underperforming the trend[7].

East Asia: Firmly in Stage 5, the region experienced a very swift demographic transition, as evidenced by the rapid increase in median age starting in the 1980s. The region is now also rapidly progressing along the Second Demographic Transition. As expected, Japan, a country with persistent sub-replacement fertility, is experiencing structurally sluggish growth (Yoshino & Taghizageh-Hesary, 2016).

Southeast Asia: The region is broadly in Stage 3 to Stage 4 of the transition and not too far ahead of neighbouring South Asia's own demographic transition. As expected, the region has also surged ahead of South Asia in terms of economic performance. Within Southeast Asia, Singapore offers another case study in anomalous transitions. Being in the tropics, the nation was encumbered with the same higher pathogenic burden that has inhibited much of tropical world's demographic transition. Despite this however, Singapore has experienced a much-accelerated demographic transition and even faster economic growth. This irregular result can be plausibly explained by the fact that Singapore's labour force was significantly constituted through inward skilled migration (Pan & Theseira, 2023). In contrast, other tropical regions have had to rely on achieving a more *organic* demographic transition by relying on their younger indigenous population. The case of Singapore provides insight into how transformative skilled migration can be for a society's demo-economic transition. Accordingly, it also highlights the economic costs of mass skilled emigration (brain drain) for nations on the losing leg of the transfer.

Europe: Being the first region to experience the modern demographic transition, Europe was endowed with a markedly higher economic age for a much longer time. Moreover, Europe remains a significant recipient of skilled labour, further propelling its economic performance. This partially

[7] This specific language of nations underperforming/overperforming their demo-economic transition stage peers is more empirically precise and hence preferable to the more prevalent terminology of nations *harnessing* or *missing* the dividend.

explains the region's superior economic development. However, even within Europe there have been noticeable differences with Western European countries performing discernibly better than those in the East or South regardless of age structure. The reasons for this difference are numerous and not within the scope of this paper. The result however highlights once again the ability of nations to over or underperform their demo-economic transition depending on other factors.

Sub-Sahara Africa: As far back as the 50s, tropical Africa possessed the youngest age structure. This is further substantiated by the lower life expectancy of the region compared to others dating as far back as the 19th century (Riley, 2005). Furthermore, the region's fertility transition remains sluggish (Bongaarts & Casterline, 2013). This is due to various factors such as gender-stratification and pervasive poverty (Makinwa-Adebusoye, 2001). Resultantly, Africa's demographic (and therefore economic) transition has been slower. This sufficiently explains the region's historic and current economic malaise. A poignant finding as presented in **Table 2** is that since 1950, the world was just as poor as SSA when they were equally as young as SSA, as measured by real GDP per capita. This buttresses the thesis that economic age, at the lower extremes, imposes increasingly strong and deterministic forces on economic performance.

Country	Population, millions (2019)	Share of world population (2019)	Most recent year when median age was ~17.6†	Median age in that year	Real GDP per capita (2015) in that year
China	1,424	18.2%	1970	18.0	1,293
India	1,389	17.8%	1969	18.2	1,443
Indonesia	272	3.5%	1974	17.8	1,756
Pakistan	231	3.0%	2003	17.7	2,905
Brazil	207	2.7%	1972	17.7	4,466
Bangladesh	165	2.1%	1992	17.7	1,563
Mexico	126	1.6%	1986	17.7	12,008
Philippines	111	1.4%	1984	17.6	3,264
Egypt	108	1.4%	1966	18.0	948
Vietnam	97	1.2%	1974	17.6	1,239
Iran	87	1.1%	1994	17.7	5,340
Thailand	72	0.9%	1976	17.6	3,015
Population-weighted averages (weighted by 2019 populations)				**18.0**	**2,088**
Sub-Sahara Africa (SSA) population-weighted average (2019)				**17.6**	**3,837**

† 17.63 being the median age of SSA in 2019

***Table 2**: Table comparing economic development (proxied by real GDP per capita) of 12 of the most populous non-Western nations with SSA. The bottom 2 rows show that when these 12 nations were just as young as Africa was in 2019 (median age of 17.6), they were just as poorly developed | Sources: UN, Feenstra et al.*

The underlying factors impeding Africa's transition are slower fertility decline, higher disease burden and, to a lesser degree, emigration. Pursuing the demographic transition should therefore be a strategic economic priority for Africa. Issues such as gender equity and healthcare should ideally be considered matters of economic development and not just human rights[8]. Essentially, Africa is poor because Africa is young. This contrasts strongly with the oft-cited hypothesis of weak institutions as the causal factor behind SSA's economic situation (Acemoglu & Robinson,

[8] Gender equality is, most importantly, a human rights issue. The point here is that it should *also* be treated as an economic priority.

2010)[9]. As highlighted in Chapter II, institutional quality is itself a partial function of economic age. By extension, other political science theories of corruption or leadership as the causal factor (Amadi & Ekekwe, 2014) can also be challenged. This does not mean that SSA does not suffer from unique challenges emanating from governance and institutions. Rather, this implies that such issues may very well be attributed to the underlying demographic disequilibrium[10].

Finally, within the framework of causal analysis (Menzies & Beebee, 2024), Africa offers a more empirical argument for age structure as a causal factor. As the only major region that has yet to begin the First Demographic Transition, Africa effectively serves as the counterfactual conditional. Africa answers the question of what happens when countries do not undergo the demographic transition. The answer is economic stagnation.

The Eberstadtian

A more generic framework of this demo-economic transition can now be derived as per **Figure 20**. Inspiration for this schema was gleaned from Dr Nicholas Eberstadt who states, "*population change, slowly and gradually but also quite unforgivingly, changes the realm of the possible in social, economic, and global affairs*." (Eberstadt, 2023).

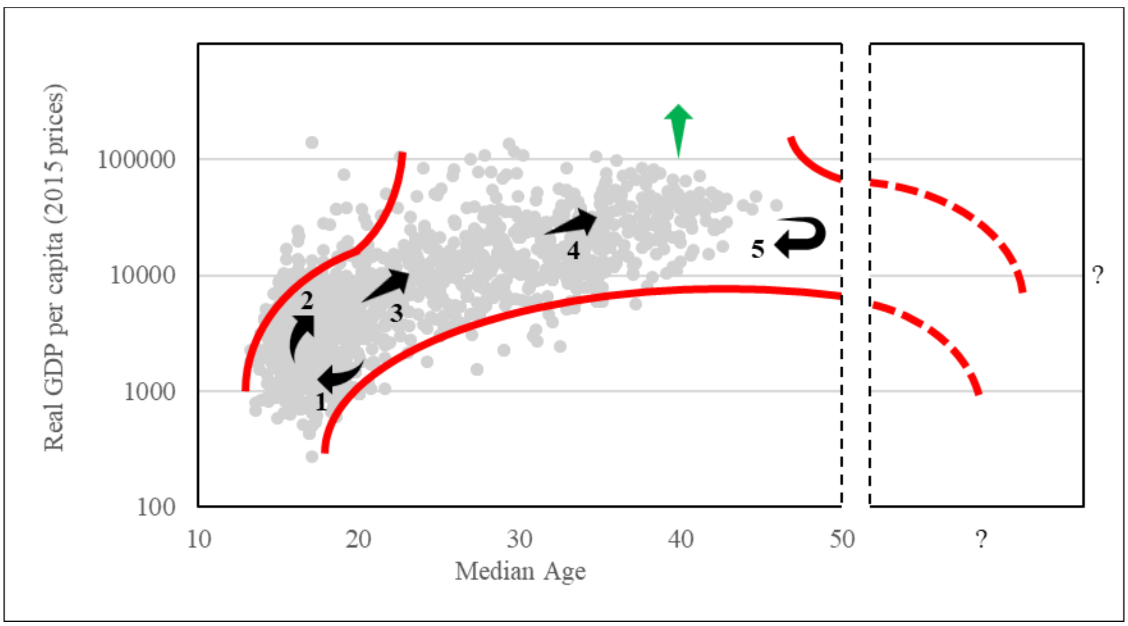


Figure 20*: The Eberstadtian. Illustrative outer bold boundaries represent the Eberstadtian realm of possibilities. Each numbered arrow and accompanying number represents the estimated transition stage. A hypothetical replacement fertility "equilibrium" growth path is represented by the upward-facing arrow.*

[9] Acemoglu et al. were almost right. Settler mortality was a step in the right direction. However, mortality is the fundamental causal force, not institutions.

[10] A practical example might be a civil servant seeking a bribe. In a very young country, the ratio of skilled workers per capita (and hence tax revenue per capita) may be so low that the state will struggle to employ the right number of civil servants, let alone pay them well. Hence, this 'corrupt' worker may be merely acting out of desperation or frustration due to difficult working conditions as opposed to some structural behavioural or moral deficit as conjectured by the political science literature.

Population change in this case refers to economic age as approximated by the *slowly and gradually* changing median age. This exerts *unforgivingly* strong forces on the *realm of the possible* outcomes as illustrated with this the bold boundaries overlaid on the data points – a confidence interval of sorts. The Eberstadtian thus represents a stochastic field of possibilities through which economies transition from being poor and young to being older and richer.

In the initial Stage 0 to Stage 1 phase of the demographic transition (arrow 1), the surging infant cohort depresses economic age, imposing contractionary forces on the economy.

From Stage 2 to Stage 3 (arrows 2 and 3), surging economic age propels economic growth as the bulk of the population transitions from adolescence to adulthood.

Between the mid-twenties and mid-forties, Stage 3 to Stage 5 (arrows 3 and 5), the correlation between growth and age structure weakens as other factors play a more important role. This is because the ratio of adults per capita generally plateaus as the society ages. Yet societies that have transitioned into this *realm* still possess superior economic performance to those in the earlier transition, again highlighting that the demographic transition does indeed confer some manner of a persistent economic stimulus.

For the Stage 5 (sub-replacement) economy, contractionary forces return once again as economic age recedes. And as evidenced by these empirical results, a credible case can be made that this process is underway in some mature major economies such as Japan, Spain and Italy. However, it is also these same ageing countries that are arguably better-equipped to withstand and ultimately reverse the effects of this demographic winter, hence the Stage 5 reverse arrow.

At the extremes of old age (the righthand segment of the chart), the *unforgiving* forces of demography will once again impose strong contractionary pressures on the economy as economic age collapses at an increasing rate and the aggregate marginal propensity to consume rises. This is intuitively affirmed from the underlying APF function. The precise extent, rate and timing of this demographic unravelling is however unknown. Moreover, no such modern empirical case exists. Consequently, this segment of the Eberstadtian is empirically undefined and must hence be approached with an abundance of caution. Owing to the limits to human physiology however, and in the absence of a human agency shock such as a medical miracle, decay is inexorable.

Hence, it is only sensible that human societies will seek to maintain a long-term fertility rate that ensures some semblance of population continuity. To that end, it is also reasonable to expect that as sub-replacement fertility persists, stronger economic and social incentives will be afforded to human reproduction.

Ultimately, as Dr Eberstadt himself argues, human agency must always be considered. Hence why the schematic is unbounded between the extreme age *vortexes*. Demography becomes destiny at the extremes. In the very long term, free from these extremes, the limits of economic prosperity are unbounded (the upward facing arrow).

For a more intuitive illustration of how this framework reconciles with the underlying NTA data, **Figure 21** is useful. The realm of economic possibilities (along the curved arrow) is broadly consistent with the initial NTA age profile in terms of both timing and curvature. Economic production begins in the teens and productivity rises, at a decreasing rate, into middle age.

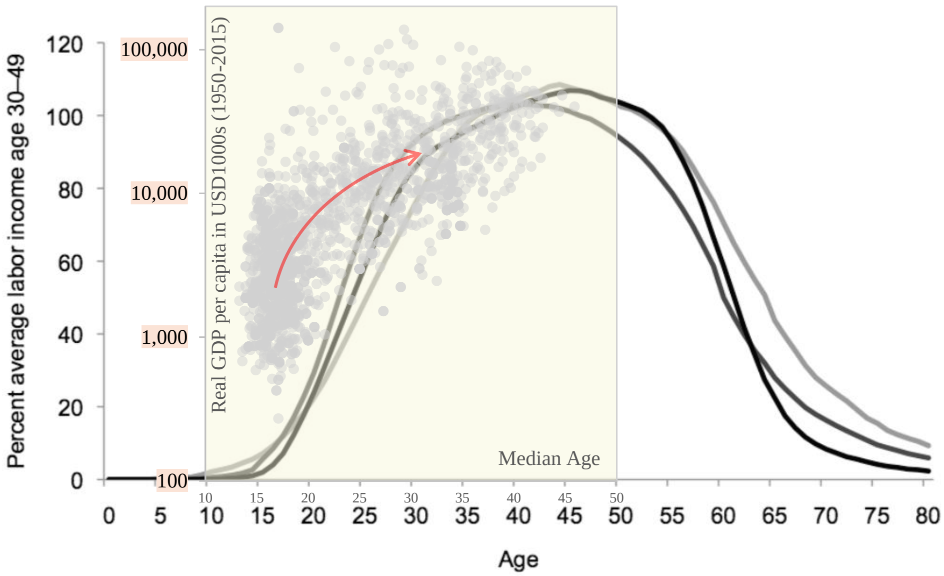


Figure 21*: The Eberstadtian stochastic process overlaid on the underlying age production function | Sources: NTA Project, UN, Feenstra et al.*

The Demographic Dividend Hypothesis – A Critique

The term *demographic dividend* has been purposefully omitted from the paper. As will be argued in this brief segment, various core aspects of the Demographic Dividend Hypothesis (DDH) are inconsistent with established science, empirically unsubstantiated, and prone to misguided policy prescriptions.

The DDH postulates that changes in age structure have no guaranteed effect on the economy and that certain policies are required to *harness* this dividend and induce economic growth. This assertion contradicts the obvious reality of human physiology: that adults are manifestly more productive than children, teenagers and the elderly (Murman, 2015). It also ignores the certainty of increasing per capita labour time given adults will *persistently* have a higher labour participation rate. The DDH posits a rather incredulous scenario of children becoming adults and being just as unproductive as they were in childhood. While this may apply to some individuals, it is quite implausible en masse. A more sensible caution the DDH should have offered is that the transition does not guarantee economic affluence but rather it guarantees a modest stimulus to economic growth, in the worst vase scenario. Growth might be low, but it is guaranteed. In a worthy bid to be cautious, the DDH erroneously contradicts the established science of human physiology and the empirical realities of labour participation.

Secondly, the hypothesis asserts that countries can fail to harness this dividend and possibly "*face costly penalties, such as rising unemployment and perhaps also higher crime rates and political instability*" (Bloom, Canning, & Sevilla, 2003). This is not supported by the empirical evidence (Fluckiger & Ludwig, 2018). Even among some of the worst performing mid/post-transition economies such as Argentina, Iran and Myanmar, a level of economic productivity and stability has been secured that comfortably exceeds that of pre-transition economies such as Niger, Central African Republic and Chad. A more sensible caution would be that a youth bulge may impose *transitory* social, political and economic costs as the economy attempts to absorb them into the labour force.

More worryingly, the DDH is occasionally utilised to unduly catastrophise pre-transition countries with threats of supposed economic non-performance unless such countries swiftly adopt a bevy of policies typically favoured by foreign organisations and countries (Foley, 2022). This leads to potentially reckless prognostications. The caution, for example, that Africa might miss the dividend and instead face demographic disaster (Canning, Raja, & Yazbeck, 2015) is particularly problematic. The empirical evidence for this is simply lacking. The Eberstadtian process in Africa holds firm, with the most prosperous African locations (national or subnational) also being the most demographically mature. By outright refuting the guaranteed and positive economic benefits of the demographic transition, this dividend catastrophism potentially compromises ongoing critical efforts towards improving healthcare and women's rights in the region. It also sets pre-transition nations up for continued stagnation given the very limited options for economic growth outside of the demographic transition.

Fourthly, the DDH fails to capture the endogenous nature of age structure. For example, dividend catastrophism asserts that demography-induced growth might be missed due to a failure to create jobs for the burgeoning young population. This fails to consider the fact that jobs themselves, being a function of entrepreneurship and capital, are generated by adults. All the complementary factors necessary to harness this dividend are themselves partial functions of age structure.

Lastly, the DDH lacks a universally-accepted methodology or empirical model of historic dividends *captured* or *missed*. There is also not much in the way of comprehensive peer-reviewed records of how well these supposed dividend-harnessing policies perform across regions and time. In contrast, the Eberstadtian process demonstrates that regardless of the quality of institutions and the supposed ability to harness this dividend, the demographic transition does promise growth and is the only guaranteed channel through which nations can sustainably transition to prosperity.

Chapter V: Policy

Nihil per contentionem, neque per inanem gloriam: sed in humilitate superiores sibi invicem arbitrantes

This chapter's focus is on fertility and migration policies. Fertility policy will be analysed through the perspective of gender equity. In the case of migration, the focus will be on skilled international migration, more specifically, the phenomenon of the brain drain.

Regarding mortality, healthcare policies are already broadly aligned towards maximising economic age and continue to play a significant role improving human welfare (Koppaka, 2011) (Durrani, 2016). The positive relationship between health outcomes and economic growth is also well-substantiated in the literature (Bloom, Canning, & Sevilla, 2004) (Piabuo & Tieguhong, 2017).

Fertility and Gender Equity

Given the adverse economic consequences of having an exceptionally low or high economic age, a sustainable economy requires some semblance of near-replacement fertility rate. Migration is an unsustainable solution given it merely transfers the sub-replacement problem to the migrant-sending country. And with global fertility declining, the pool of potential migrants is finite and dwindling.

Despite this need for a stable age structure, natalism policy is still evolving and has generally not yet achieved this result of replacement fertility. This is for a variety of reasons. Natalist policies have historically focused on solving the challenges of persistently high fertility. The existence of natural limits to human population and the means with which to estimate this human *carrying capacity* is substantiated in the literature (Rees, 1996) (Rees & Wackernagel, 2005). However, buoyed in part by the 1960s overpopulation alarmism of Paul Erlich (Erlich & Erlich, 1968), many of these natalism policies took on a more coercive and injurious direction (Zubrin, 2012). Conversely, fears of underpopulation have been persistent throughout history (Coleman & Rowthorn, 2011). As before, there are legitimate concerns surrounding persistently low and declining fertility rates (Keynes, 1978) (Christensen, Dolbhammer, Rau, & Vaupel, 2009). However, some of these concerns can metastasise into unproductive and pernicious narratives such as ageism (Katz, 1992), conspiracy (Obadi, Kunst, Ozer, & Kimel, 2022), stigmatisation (Park, 2002), and threats to women's bodily autonomy and rights (Meyers, 2001).

As one might expect, this is a difficult topic to broach. Nevertheless, the feminist literature does offer a coherent framework through which to diagnose and potentially solve the challenge of declining fertility. The feminist perspective first critiques patriarchy as a socioeconomic construct that unduly places the cost of reproduction on women specifically (Folbre, 1983) (England & Folbre, 1999) (Phan, 2013). The feminist economist perspective also recognises reproduction as an uncompensated form of economic activity (Folbre, 1994) (Baker, et al., 2023). Feminists rightly note that women, and people generally, possess no bio-essential directive to rear children (Shahvisi, 2020) (Rankin, Krouskop, & Fisher, 2024). Ergo, the feminist perspective conceives declining fertility as a natural consequence of a patriarchal system that fails to fully recognise human reproduction as the fundamental economic activity it is.

This critique excels for a variety of reasons:

1. The critique is consistent with the neoclassical framework's rational economic agent hypothesis. Regardless of being the owners of the means of reproduction, women of child-rearing age act in their economic self-interest by focusing their discretionary time towards activities that yield utility through economic compensation.
2. The above argument adequately explains the ongoing collapse in fertility rates. In the absence of direct economic incentives or benefits, and irrespective of undue social and political pressures, an eventual trend towards near-zero fertility is expected. In effect, a woman (and any other rational economic agent) that chooses to be child-free is merely maximising their lifetime utility as prescribed by the prevailing economic incentives.
3. The critique offers a potential solution to this fertility decline: women. As owners of the means of reproduction, and as enshrined in the fundamental human right of bodily autonomy, it is women themselves who are best-positioned to develop and help actualise the solution.

It is evident that the cost of fertility cannot rest solely on the shoulders of women, or parents in general. Especially when children function as a social good as opposed to a private one as was the case in pre-urbanised societies (Minge-Kalman, 1978). It really does take a village to raise a child. And given this persistent and justified decline in fertility, as the gender experts Drs England and Folbre write, "*how much is collectively invested in children will prove to be an important determinant of the fate of nations in the next century*" (England & Folbre, 2002).

Migration and the Brain Drain

Modern economic migration is characterised by the movement of skilled labour from low- and middle-income nations to higher-income ones. These less wealthy source nations also tend to be younger (lower economic age) than the wealthier and older host nations though there are exceptions such as countries in Eastern and Southern Europe.

One body of literature purports that source nations experience a net gain from this brain drain due to aid, remittances, FDI, trade and knowledge transfers (D'Agosto, Solferino, & Tria, 2006) (Mayr & Peri, 2008) (Beine, Docquier, & Oden-Defoort, 2011) (Docquier & Rapoport, 2012). However, the benefits of this *brain gain*, which are completely discretionary and outside the control of the source nations, is disputed (Schiff, 2005) (van der Linden, 2005). And in the medical sector specifically, the effects of the brain drain have proven devastating especially for low-income nations (Dzinamarira & Musuka, 2021) (Lawal, et al., 2022). Resultantly, there is no formal consensus on the matter. This is exacerbated by the fact that no universally accepted migration accounting framework exists.

In this regard, the Macroeconomic Intergenerational Framework excels by better highlighting the lifetime economic costs and gains emanating from the brain drain. In **Figure 22**, the brain drain has been illustrated as a permanent and uniformly proportionate decline in the population of the source nation starting with young workers.

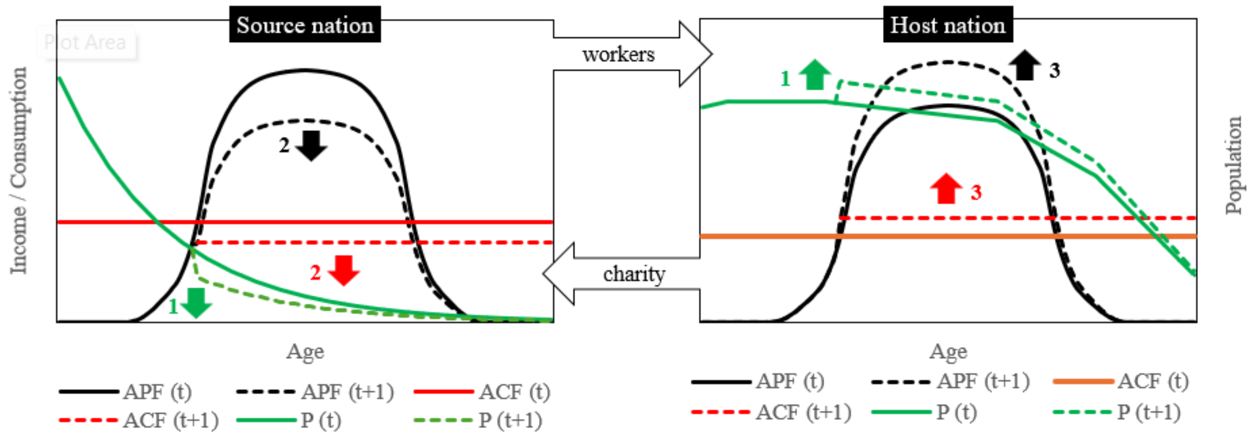


Figure 22*: An illustration of the brain drain using the Macroeconomic Intergenerational Framework. The lower-income pre/early-transition source nations transfers workers to wealthier late-stage transition economies (1). In doing so, source nation labour productivity and consumption decline (2). The host nation's productivity and consumption increases (3). In exchange, the source nation receives charity (aid and remittances).*

As illustrated, the brain drain has the following direct effects:

1. Human capital transfer: the source nation experiences a decline in their adult population [*Source: P(t) to P(t+1)*] while the host nation experiences the opposite [*Host: P(t) to P(t+1)*].
2. Productivity transfer: poorer and younger countries, which already have significant human capital deficits, experience a decline in their average productivity as their native population is effectively de-skilled [*Source: APF(t) to APF(t+1)*]. A few high-income nations, already endowed with a superior share of human capital, see their skilled labour force expand [*Host: APF(t) to APF(t+1)*]. Over time, the source country's economic growth rate also decelerates as economic age declines.
3. Utility transfer: With less production to go round, average consumption also declines for the source nation [*Source: ACF(t) to ACF(t+1)*] while the host can afford more consumption [*Host: ACF(t) to ACF(t+1)*]. This functions as a utility transfer from the source to the host.
4. Compensatory transfers: the source country also receives compensation primarily in the form of aid from the host and remittances from the emigrants. These transfers are entirely voluntary however and solely at the discretion of the host nation and its migrant workers. These parties have no enforceable obligation to recompense the source. Moreover, no robust and universally accepted accounting methodology exists to ascertain the costs and necessary compensation for migration.

This exposition of the brain drain using Intergenerational Transfers highlights the underlying shortcomings of the current economic migration regime. In effect, the brain drain weakens and decelerates the economies of lower income countries, compelling them to instead depend on the indeterminate benevolence of higher-income host nations[11]. Given this lopsided balance of

[11] Aid is not only inherently uncertain but also comes with other questionable interventions. For example, Brown University (Brown University, 2024) estimates that the United States of America has spent over USD1 trillion on post-9/11 wars focused mostly on the Global South. This exceeds the USA's plus-USD750 billion in expenditures on

bargaining power, lack of a mutually-acceptable accounting framework, and the absence of enforceable compensation, the brain drain is more akin to a Faustian bargain than a mutually beneficial concord. As others have argued, it is a form of economic exploitation (Bou-Habib, 2021).

It is worth noting that the critique here is not of migration in general, but rather the practice of extractive economic migration across international borders. Within-country economic migration poses no such challenges because of shared institutions and the robust implicit and explicit agreements that ensure all the nation's inhabitants benefit from the economy regardless of their location. However, no such agreements exist when it comes to international economic migration.

Policy Guidance

At their core, the modern fertility and economic migration regimes are economically unsustainable because they operate as systems of economic expropriation – women procreating for men, the poor procreating for the rich.

The goal of this chapter is not necessarily to recommend specific policies but rather to highlight the inherently flawed nature of these systems especially given the manifest need for a stable long-run age structure.

The contemporary migration regime effectively threatens poorer nations' prospects for a productive demographic transition, forcing such countries to instead rely on unenforceable mechanisms of recompense.

With regards to fertility however, the scale of expropriation is markedly more pronounced. While economic migrants comprise a very small portion of the human population, women (most of whom will or have been mothers) account for half the species. And unlike economic migration, where these *benevolence transfers* somewhat ameliorate the cost, few such transfers are consistently and reliably availed to those engaged in child rearing, especially mothers. Even if they were, the problem of benevolence dependency would still apply. In addition, this motherhood cost is less contested and measurably high (Grimshaw & Rubery, 2015). And while there exists a healthy scholarly debate as to how best to compensate brain-drained nations, arguments in favour of comprehensively occupationalising child rearing are markedly underdeveloped within the literature and general discourse.

Given the lack of a voluntary agreements and fair compensation, it would be ill-advised for any sovereign territory to rely on current fertility and migration trends to hold. Both women and migrant-sending countries have justifiable grounds and the means to limit their supply of future potential workers.

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development aid since the September 11 Attacks (CFR, 2023), with a generous share of that going to nations that don't supply much in the way of skilled workers to the USA.

Chapter VI: Conclusion

Gratia Domini nostri Jesu Christi, et caritas Dei, et communicatio Sancti Spiritus sit cum omnibus vobis.

Limitations of the Theory and Model

The Lee-Mason model, the four Propositions and the general thesis of causality and endogeneity all have various limitations.

Firstly, the APF function is based on incomplete data. The NTA Project is an ongoing effort, and data is still being collected and processed. Various territories and time periods are not yet included. Readers should hence consider the various illustrations of the APF and ACF as merely demonstrative. For example, the APF presented in this paper has been illustrated as Gaussian-like, but the actual empirical function may take on a more trapezoidal or squircular form.

Secondly, the reliance on estimators limits the accuracy and reliability of statistical inference. As discussed in Appendix D: Estimators, these estimators all have various drawbacks that compromise empirical estimation. Median age will tend to underestimate economic age in cases where the working age population is unnaturally large, for example in oil-rich high-immigration countries. Conversely, economic age will be overestimated in countries experiencing a high rate of skilled emigration such as Haiti and Lesotho.

Proposition IV, that age structure has played a key role in influencing historic human economic variation, is nearly impossible to definitively prove. This is because of the inherent difficulty of accurately measuring age structures and economic development for much of the world prior to the 20th century. Moreover, while a robust case has been made for age structure, other factors and events such as industrialisation, war and imperialism have played significant roles in shaping global economic variation. Indeed, there are numerous instances of other factors playing a stronger role in shaping ancient economic divergence. The fact that the First Agricultural Revolution happened in Mesopotamia (ancient Iraq) serves as a good example. Located along the Fertile Crescent of West Asia, the region's biodiversity and pathogenic burden likely exceeded that of more populated and demographically mature regions such as those in Europe and East Asia. And yet despite this apparent disadvantage in economic age and size, the ancient Mesopotamians presided over a cradle of civilisation that emerged thousands of years before similarly advanced societies throughout the rest of the world.

Proposition IV is also challenged by the fact that regions with arguably the lowest pathogenic burdens, the polar regions, did not develop quicker than others. This however can be partially explained by the concomitant scarcity of arable land and biomass. This would have conceivably limited not only the population size but also the ability to develop agriculture and hence expand their societies.

Being a function of fertility, mortality and migration, economic age is a complex variable requiring a rigorous multidisciplinary approach. It is simply not feasible for this single paper to comprehensively explore how each of these disciplines influences economic age.

In addition, the inherent endogeneity of economic age makes statistical inference a delicate and laborious task. While the Eberstadtian serves as a useful framework, especially for a less technical audience, it lacks the granularity and precision necessary to accurately quantify the causal effect of age structure on economic growth and productivity.

Further Research

The NTA Project has been an indispensable tool and source of insight. Continuance of the project is essential for a more detailed understanding of how age structure interacts with economic activity.

In the absence of accurate estimates of economic age, studies evaluating multiple estimators would be most instructive. This would also help establish a set of methodological best practices. For now, *skilled healthy urban economic age* is likely the most robust subcomponent. Estimators that can capture the essence of these subcomponents of health, education and urbanisation (access to modern amenities) would be most useful.

This paper focused on making a case for causality between age structure and economic productivity. However, with age structure being a function of primarily fertility and mortality, a similar argument for causality applies for these two factors. In terms of mortality, much (certainly not all) of the economic prosperity achieved in recent history can be attributed to advancements in healthcare, more specifically the advent of antipathogenic medicines. This factor also offers insight into how ageing societies can economically thrive in the face of sub-replacement fertility. Just as declining child mortality induced a sharp increase in economic age, so too can advances in anti-ageing technology ameliorate and perhaps even overcome the impact of declining fertility and population. Similarly, the emancipation of women can be argued to have increased the per capita labour participation rate (effectively an increase in economic age), thus acting as a second key catalyst for modern economic prosperity. And has been argued earlier, continued progress towards gender equality, especially in child rearing, is crucial for stabilising fertility rates and securing long term growth. Healthcare and gender equality are more than just humanitarian issues. They represent causal forces essential for economic growth. This entire paper merely constructs a framework through which these more fundamental forces of fertility and mortality affect the economy. Hence why further research on these two topics is crucial.

Summary

Population age structure does indeed have a causal effect on aggregate economic productivity. Age governs human physiological fitness and labour participation, key drivers of economic productivity and general human agency. Regarding the long-term causal mechanism, the ratio of adults per capita has a positive and deterministic effect on the ratio of workers per capita. While factors such as policies and institutions affect the absorption of adults into the labour force, this positive relationship between the stock of adults and workers does hold over time.

This specific effect of age structure on economic productivity is captured by the following two provable propositions:

Proposition I: (the participation effect)	The more adults per capita, then the more economic output per capita *ceteris paribus*.
Proposition II: (the growth effect)	The more adults per capita, the higher the aggregate savings rate, and hence the rate of economic growth, *ceteris paribus*.

Building on these propositions, the paper is novel in various ways:

1. Synthesis of a new demographic macroeconomic framework, the Lee-Mason model. This quantitative model, derived from the intergenerational economics literature of Profs Ronald Lee and Andrew Mason, more accurately evaluates the effect of age structure on macroeconomic productivity.
2. Within this model, a novel variable called economic age has been derived. It measures the stock of human capital against the total population while accounting for the heterogeneity of productivity across age – as influenced by both physiological and sociological factors. In this way, it offers a more precise evaluation of the age structure effect compared to other estimators such as dependency and support ratios.
3. The model achieves full spectrum neoclassical integration as well as a reconciliation with the discipline of feminist economics. The model also validates Unified Growth Theory and outperforms the contemporary Demographic Dividend Hypothesis in both intellectual and empirical substantiation.

The underlying theory is validated through a stochastic process that measures per capita economic production as a function of median age across time. A summarised version of the model is presented in **Figure 23**. The model confirms the paper's thesis. The further along the demographic transition, up to a certain point, the greater the nation's prosperity and growth. While the transition does not guarantee prosperity, it does guarantee a higher level of economic productivity and growth, and it remains the only universally-accessible path through which nations can become high-income economies.

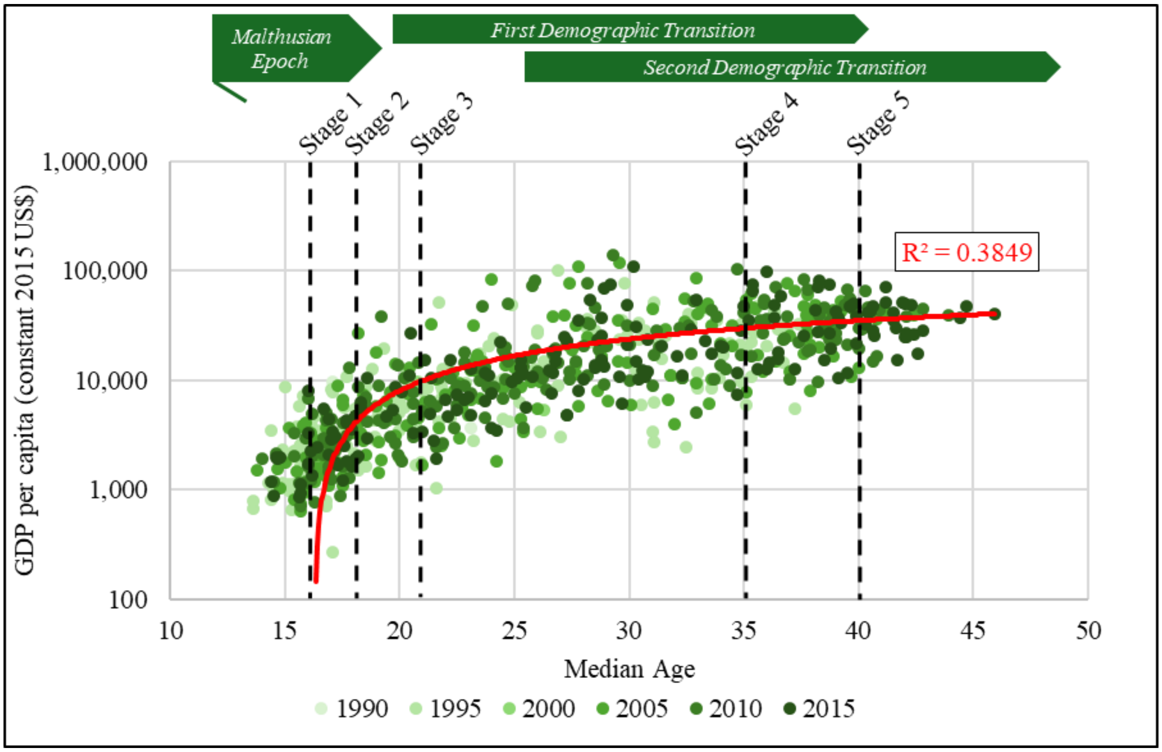

Figure 23*: Stochastic process of national per capita income (y-axis) across time (light to dark) and across median age (x-axis). A logarithmic trend line (2015) is included for illustration. This covers 180 countries over 25 years | Sources: UN, Feenstra et al.*

It is also observed and deduced that at these boundaries of age, minor shifts in age structure induce disproportionally larger changes in economic productivity. Demography is not destiny. Once a country escapes the Malthusian epoch, growth is guaranteed but prosperity now depends on other factors. At the extremes however, demography does indeed become a deterministic force. These findings give rise to a range of insights:

1. **Proposition III**: the demographic transition is also an economic transition. It would explain why almost no nation has ever achieved modern economic prosperity without undergoing the First Demographic Transition.
2. **Proposition IV**: variations in age structure explain a significant portion of ancient economic divergences. Owing to the virulence of disease and accompanying lack of modern antipathogenic solutions, humanity has historically persisted at very young age structures. Hence, economic productivity and growth has historically been subdued and more sensitive to discrepancies in age structure.
3. The Global South vs North Divide: Because equatorial regions have carried much higher environmental pathogenic burdens, it partially explains why societies in such locations have typically developed at a slower pace. This effect has been amplified by other factors, such as discrepancies in global healthcare distribution. A slower demographic transition offers a credible answer to the conundrum of the Africa's sluggish economic progress. A case is made that Africa is not impoverished because of institutions, leadership or policy failure. Rather, owing to having the highest pathogen burden known to mankind, the

continent is simply still too young. Africa is as poor as every nation was at that same stage of the demographic transition.

4. Age structure can also better explain other modern economic variations. Western economies, being the first to undergo the demographic transition and being major recipients of skilled workers, owe much of their continued economic performance to this sustained demographic subsidy. Consistent with the existing literature, East Asia's rapid demographic transition also helps explain the region's sharp economic expansion. Other subregions of South Asia, South-East Asia, the Caribbean and Latin America have median ages around the 20s and early 30s, validating their status as rising middle income economies.
5. Persistent sub-replacement fertility will eventually induce slower economic growth, even with robust immigration. Coupled with declining population, this may also moderate aggregate economic activity. The timing and extent of these effects however is still debated, uncertain and varied. Moreover, the trend is reversible and not permanent. Therefore, this should not be construed as a cause for alarmism.

With regards to policy, a case is made that economies take active steps to achieve and preserve a viable age structure while also recognising and upholding the rights and entitlements of those most heavily involved in the activity of child rearing and care. In this regard, policies surrounding fertility and migration require urgent reform as they are currently unsustainable and essentially function as forms of economic expropriation. Fertility entails the uncompensated extraction of child rearing services from mostly mothers. Migration entails the extraction of human capital and future economic growth from mostly lower income nations, while simultaneously imposing economic dependence (reliance on aid and remittances) on them. Of these, the modern fertility regime presents a far more pressing socioeconomic challenge. As per the feminist critique, declining fertility can be considered a natural consequence of an extractive fertility regime. Ideally, child rearing should be recognised as the economic activity it is, warranting significantly greater social support and economic recognition.

Finally, given the causality of age, the reality is that fertility and healthcare are, by definition, the true underlying causal forces. Hence, much of modern economic prosperity can be attributed to advances in antipathogenic technology and women's emancipation.

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Appendices

Appendix A: Epigraph

Epigraphs for chapters I, III, IV, V and VI are from the Latin version of the Holy Christian Bible, the Biblia Sacra iuxta vulgatam versionem. The corresponding English translation is from the New International Version of the Bible. The chapter II epigraph is from the Meditations of Marcus Aurelius in M. Antonius Imperator Ad Se Ipsum by Jan Hendrik Leopold, translation by Arthur Spenser Loat Farquharson.

Chapter	Source	Modern English translation
I	1 Corinthians 13:11	When I was a child, I talked like a child, I thought like a child, I reasoned like a child. When I became a man, I put the ways of childhood behind me.
II	Book 8: Verse 13	Continually and, if possible, on the occasion of every imagination, test it by natural science, by psychology, by logic.
III	Ecclesiastes 3:1	There is a time for everything.
IV	Luke 12:2	There is nothing concealed that will not be disclosed or hidden that will not be made known.
V	Philippians 2:3	Do nothing out of selfish ambition or vain conceit. Rather, in humility value others above yourselves.
IV	2 Corinthians 13:14	May the grace of the Lord Jesus Christ, and the love of God, and the fellowship of the Holy Spirit be with you all.

Appendix B: Derivations

Equation (8)

$$Y'(\psi) = \frac{(1-\alpha)}{\psi^{\alpha}} > 0$$

Equation (9)

In equilibrium, $S = I = Y - C$

Substituting (8) and (3) for Y and C respectively yields:

$$S = I = AK^{\alpha}(N\psi)^{1-\alpha} - N\int_0^{\omega} c(x) \cdot p(x)\, dx$$

$$s = \frac{S}{N} = AK^{\alpha}\psi^{1-\alpha}N^{-\alpha} - c$$

$$s'(\psi) = \frac{(1-\alpha)}{\psi^{\alpha}} > 0$$

Equations (10) to (14)

Given

$$K_{t+1} = N_t s_t + K_t(1-\delta)$$

$$\kappa_{t+1} = s_t + k_t(1-\delta)$$

$$\dot{K} = Ns - \delta K$$

$$\dot{\kappa} = s - \delta\kappa$$

$$r_{\kappa} = \frac{s}{\kappa} - \delta$$

Then

$$K'(\psi) = \kappa'(\psi) = \dot{K}'(\psi) = \dot{\kappa}'(\psi) = r_{\kappa}(\psi) = \frac{(1-\alpha)}{\psi^{\alpha}} > 0$$

Equations (21) and (22)

Using the following adjusted Cobb-Douglas Function:

$$f(K, N, \psi) = K^{\alpha}(N\psi)^{1-\alpha}$$

The Law of Motion:

$$\frac{K_{t+1}}{N} = \frac{K_t}{N} + r_s\left(\frac{K_t}{N}\right)^{\alpha}\psi^{1-\alpha} - \delta\frac{K_t}{N}$$

Steady-state capital K^* is achieved when:

$$r_s \left(\frac{K^*}{N}\right)^{\alpha} \psi^{1-\alpha} = \delta \frac{K^*}{N}$$

The steady-state equations are:

$$\frac{K^*}{N} = \psi \left(\frac{r_s}{\delta}\right)^{\frac{1}{1-\alpha}}$$

$$\frac{Y^*}{N} = \psi \left(\frac{r_s}{\delta}\right)^{\frac{\alpha}{1-\alpha}}$$

The first derivatives are:

$$\kappa^{*\prime}(\psi) = \left(\frac{r_s}{\delta}\right)^{\frac{1}{1-\alpha}} > 0$$

$$y^{*\prime}(\psi) = \left(\frac{r_s}{\delta}\right)^{\frac{\alpha}{1-\alpha}} > 0$$

Appendix C: Formulae

Lee Mason model equations:

Eq.	Description and definitions	
(1)	Population - age structure identity $N = population\ size$ $p = normalised\ population\ distribution$	$N_t = N_t \int_0^{\omega} p_t(x)\, dx$
(2)	Aggregate production $Y = aggregate\ output$ $y(x) = age\ production\ function$	$Y_t(x) = N_t \int_0^{\omega} y_t(x) \cdot p_t(x)\, dx$
(3)	Aggregate consumption $AE = aggregate\ expenditure$ $c(x) = age\ consumption\ function$	$AE = N_t \int_0^{\omega} c_t(x) \cdot p_t(x)\, dx$
(4)	Lee Mason Production Function $G = normalisation\ factor$ $= \ stock\ of\ tools\ per\ capita$ $\check{y} = normalised\ age\ production\ function$	$Y_t = G_t N_t \int_0^{\omega} \check{y}_t(x) \cdot p_t(x)\, dx$
(5)	Normalised production $h(x) = physiological\ fitness\ by\ age$ $u(x) = production\ time\ by\ age$	$\check{y}_t(x) = f[h(x), u(x)]$
(6)	Economic age $\psi = Economic\ age$	$\psi = \int_0^{\omega} \check{y}_t(x) \cdot p_t(x)\, dx \equiv \frac{y_t}{G_t}$

Technology equations:

Eq.	Description and definitions	
(23)	Endogenous Technology Growth	$\dot{A} = \lambda L_A A_{t-1}$
(24)	Technology Labour	$L_{A,t} = N_t^A \psi_A$
(25)	Economic Age of Technology	$\psi_A = \int_0^{\omega} \check{a}_t(x) \cdot p_t(x)\ dx \equiv \frac{a_t}{G_t^A}$

Omnia tempus habent:

Eq.	Description and definitions	
(26)	Economic Age of Time	$\psi_\tau = \int_0^{\omega} u_t(x) \cdot p_t(x)\, dx$

Neoclassical equations:

Eq.	Description and definitions	
(7)	Labour L=Age-adjusted labour force	$L_t = N_t \int_0^{\omega} h_t(x) \cdot u_t(x) \cdot p_t(x)\, dx = N\psi$
(8)	Neoclassical synthesis	$Y_t = A_t K_t^{\alpha} (N_t \psi)^{1-\alpha}$
(9)	Savings per capita	$s_t = A_t K_t^{\alpha} \frac{\psi^{1-\alpha}}{N_t^{\alpha}} - c_t$
(10)	Total capital in next period	$K_{t+1} = N_t s_t + K_t(1-\delta)$
(11)	Capital per person in next period	$\kappa_{t+1} = s_t + k_t(1-\delta)$
(12)	Total capital added in period	$\dot{K} = \frac{\partial K}{\partial t} = N_t s_t - \delta K_t$
(13)	Capital per person added in period	$\dot{\kappa} = \frac{\partial \kappa}{\partial t} = s_t - \delta \kappa_t$
(14)	Rate of net capital accumulation	$r_{\kappa} = \frac{s_t}{\kappa_t} - \delta$
(15)	Marginal product of capital	$MPK = \frac{\partial Y}{\partial K} = \alpha A K^{\alpha-1} (N\psi)^{1-\alpha} = \alpha \frac{Y}{K}$
(16)	Neoclassical proof of Prop II	$\frac{\partial MPK}{\partial \psi} = \frac{(1-\alpha)}{\psi^{\alpha}} > 0$
(17)	Marginal product of total population growth	$MPN = \frac{\partial Y}{\partial N} = (1-\alpha) A K^{\alpha} (N\psi)^{-\alpha} \psi = (1-\alpha)\psi(A\kappa)^{\alpha}$
(18)	Marginal product of economic age	$MP\Psi = \frac{\partial Y}{\partial \psi} = (1-\alpha) A K^{\alpha} (N\psi)^{-\alpha} N = (1-\alpha) N (A\kappa)^{\alpha}$
(19)	Proof of diminishing returns with respect to additional population	$\frac{\partial^2 Y}{\partial N^2} = -\frac{\alpha(1-\alpha) A K^2 \psi^2}{(N\psi)^{(\alpha+1)}} < 0$
(20)	Proof of diminishing returns with respect to economic age	$\frac{\partial^2 Y}{\partial \psi^2} = -\frac{\alpha(1-\alpha) A K^2 N^2}{(N\psi)^{(\alpha+1)}} < 0$
(21)	Steady state capital per person	$\kappa^* = \psi \left(\frac{r_s}{\delta}\right)^{\frac{1}{1-\alpha}}$
(22)	Steady state income per person	$y^* = \psi \left(\frac{r_s}{\delta}\right)^{\frac{\alpha}{1-\alpha}}$

Appendix D: Estimators

Various economic age estimators are used throughout the literature. Below is a summary of the most common variables and an embryonic appraisal on the suitability of said variables as economic age estimators.

Appraisal of Potential Economic Age estimators

Estimator	*Advantages*	*Cons*
Median Age	Good availability; easy to understand, analyse and interpret; captures APF concavity	Overly simplistic; non-linear; biased; fails to fully capture age structure stochasticity; omits participation effect; tendency to over(under)-estimate anomalously low(high) economic age
Dependency Ratio (DR)	Availability; easy to calculate; linear; somewhat easy to understand	15-64 age band is anachronistic; overestimates economic age (15- to 25-year-olds may not be net producers); omits participation function; fails to capture APF concavity (assumes equal productivity across worker age)
Prime Age Ratio	As with the DR but more accurate as the 25-54 is an arguably more accurate net-producer age band	Poor availability; unduly ignores over-55s; still fails to capture full APF concavity
Productivity weighted labour force dependency ratio	As with DR but captures participation function of the APF; empirical accuracy	Very poor availability
Fertility rate	Availability; easy to understand; can be forward-looking; captures the economic cost of mother/parenthood	Doesn't capture actual age structure, merely a sub-function
Life Expectancy	Availability; forward-looking; very potent in estimations of ancient economic age profiles given their more homeostatic demographics	Doesn't capture actual age structure, also a sub-function

For the purposes of empirical analysis, median age was chosen because:

1. Akin to natural age, it is much more intuitive and hence easier to understand for a less technical audience. This is the primary reason.
2. It is one of the few estimators that captures APF concavity and asymmetry. This is an important attribute and avoids overestimating economic age in younger economies given such populations will naturally have a younger, and hence likely less productive, labour force. Concavity also helps to visually illustrate the underlying APF curvature as per **Figure 21**.
3. It is available for a much longer period, thus making it more reliable for longitudinal study.

Appendix E: Data

Where *y* = *real GDP* and *μ* = *median age*

	1950		1955		1960		1965		1970		1975		1980		1985		1990		1995		2000		2005		2010		2015	
	y	μ	y	μ	y	μ	y	μ	y	μ	y	μ	y	μ	y	μ	y	μ	y	μ	y	μ	y	μ	y	μ	y	μ
Albania		19.6		19.3		18.8		17.9		17.7	3385.273	18.3	3714.541	19.8	3689.646	21.5	3681.208	23.1	4391.234	24.5	5315.43	26.3	6531.797	29.1	10522.67	32.3	11644.79	34.7
Algeria		18.4		17.6	10835.01	16.2	6427.353	15.5	7780.051	15.2	10468.85	15.3	12254.75	15.5	13826.62	16.2	9721.904	17.1	8597.436	18.5	9704.585	20.7	12356.63	23.1	14808.77	24.7	12512.01	26.5
Angola		18.9		18.8		18.3		16.9	4842.227	15.4	4346.994	15.5	3467.98	15.8	3309.231	16.0	3037.319	15.6	2293.484	15.4	2228.591	15.6	4116.556	15.9	6834.37	16.0	8058.727	16.0
Anguilla		18.9		16.8		15.9		16.3	10036.48	16.5	11091.43	17.1	13551.98	19.5	15906.64	21.5	27838.92	23.9	27267.07	26.0	27215.84	27.7	35076.99	29.5	28403.24	31.2	17478.21	33.6
Antigua and Barbuc		18.0		17.8		18.2		17.9	6234.454	16.6	7196.724	18.0	7961.821	19.9	8301.26	22.4	13509.29	24.5	12543.14	25.9	15362.21	27.3	16398.4	28.8	21019.09	30.0	16416.92	32.1
Argentina		24.4		25.0		25.5		25.7		25.8	4296.975	25.9	4492.146	25.9	4955.895	26.0	6260.611	26.2	12187.8	26.4	14332.45	26.8	14113.85	27.7	19190.5	28.7	21197.79	29.9
Armenia		21.1		21.7		21.8		20.8		20.0		20.9		22.2		24.0		25.7	3076.116	27.0	3798.665	28.7	6023.919	30.1	8880.064	31.0	11156.54	32.3
Aruba		17.3		17.2		17.3		17.6		19.1	11738.9	21.0	18259.44	24.1	26849.02	27.1	48472.41	30.4	52090.98	31.1	45452.68	33.0	45670.03	35.4	38688.96	36.9	37580.47	39.1
Australia	13660.78	29.4	14775.68	29.2	15799.37	28.6	17704.11	27.3	21518.93	26.6	22008.21	27.1	24692.65	28.4	26544.85	29.8	29933.85	31.1	33466.84	32.7	39331.9	34.4	45488.26	35.5	50222.52	35.9	48712.19	36.3
Austria	5959.964	34.8	7942.937	34.1	10212.93	34.5	12086.68	34.0	14843.68	32.7	17835.41	33.0	20080.34	33.6	20841.47	34.2	26615.16	34.6	31342.95	35.3	38036.57	37.1	43298.79	38.9	45806.35	40.4	49618.7	42.0
Azerbaijan		20.4		20.6		20.4		16.5		16.3		17.6		19.9		21.5	10497.03	22.4	2779.117	23.2	2816.329	24.5	5500.551	26.0	14367.47	26.9	14581.19	28.8
Bahamas		20.0		19.0		18.6		18.4	28157.6	17.8	17916.19	18.7	28855.23	20.3	31468.49	21.5	29458.39	22.8	24513.11	24.1	35694.67	25.7	39094.72	27.2	33069.75	28.2	30962.69	30.3
Bahrain		17.8		17.4		17.2		16.9	21807.44	16.3	23411.39	18.0	26382	20.7	10468.51	21.9	15927.09	23.5	17423.26	23.5	27777.15	25.0	38436.68	26.7	46553.12	28.5	48509.74	29.9
Bangladesh		18.3		18.2	1563.253	17.8	1553.017	17.3	1566.89	16.6	1141.59	16.1	1333.432	16.4	1393.286	16.5	1531.382	17.2	1648.079	18.4	1520.245	19.7	1666.417	21.0	2650.664	21.9	3714.801	24.0
Barbados		21.8		21.5	9351.603	21.7	10169.5	20.4	15426.25	20.5	16529.91	21.8	12789.05	23.7	11801.51	26.0	15811.57	28.2	23666.1	30.4	23597.75	32.4	22032.34	34.0	16825.59	35.3	12689.14	37.2
Belarus		25.2		24.8		25.5		26.9		28.9		29.2		29.9		30.8	14331.13	31.9	8409.264	33.6		35.5	12043.06	37.0	18824.51	37.9	19728.43	38.8
Belgium	8348.565	34.6	9757.859	33.6	10628.08	33.9	13103.9	33.8	16048.81	33.5	19349.27	33.1	23806.79	33.2	20143.09	34.2	26114.31	35.3	29060.27	36.5	33739.33	37.9	40701.17	39.1	44733.91	39.8	42891.36	40.5
Belize		19.5		18.1		16.8		15.0	3987.867	14.3	4506.18	14.6	5292.127	15.3	4750.915	16.2	7192.621	16.6	7794.756	17.1	6530.451	18.6	7805.492	19.6	7784.203	20.6	6594.822	22.8
Benin		23.1		21.5	1780.014	20.1	1889.054	19.0	2198.189	17.7	2079.811	16.9	2214.156	16.4	2021.059	16.2	1348.43	16.0	1316.472	16.1	1695.303	16.2	2065.676	16.5	2078.012	16.7	3072.494	17.2
Bermuda		24.1		24.0		24.6		24.5	11249.9	25.7	14165.71	27.2		28.9		30.3		31.7		33.5		35.8	41300.83	38.0	66545.41	39.5	48334.65	42.3
Bhutan		17.0		17.8		18.4		18.9	1989.118	19.2	1818.371	18.8	2085.95	18.3	2702.984	18.0	2956.53	18.0	3242.181	18.3	4428.868	19.3	6264.483	21.1	8901.771	22.5	9778.855	24.9
Bolivia	2430.723	19.6	2214.553	19.0	1958.691	18.5	2254.911	18.4	2094.856	18.3	2491.303	18.1	2474.812	18.2	2471.14	18.3	2334.64	18.4	3056.615	18.9	3264.686	19.6	3896.658	20.3	5248.621	21.0	7336.276	22.5
Bosnia and Herzeg		18.9		19.6		20.5		20.6		21.2		22.8		24.9		26.9		29.0	2458.73	32.5	6590.929	32.9	7924.769	35.1	10212.63	37.0	11810.19	39.5
Botswana		17.9		17.5	513.3026	16.5	588.3717	14.9	828.0857	13.9	1719.98	14.6	2597.815	15.3	4591.731	15.6	7205.669	16.0	8272.153	17.0	11064.16	18.4	14003.92	19.8	14527.12	20.8	15194.87	22.2
Brazil	1664.83	17.5	1981.277	17.3	2336.85	16.9	2937.486	16.8	3726.383	17.3	5355.223	18.2	5876.957	19.2	5942.824	20.3	6406.385	21.5	9343.925	22.9	9460.318	24.3	9686.668	26.1	15012.52	27.7	15077.58	30.3
British Virgin Island		17.6		15.8		15.2		16.8	7778.401	15.1	7623.101	18.7	10376.45	22.2	8587.797	23.5	11463.71	25.9	36508.86	28.2	48253.14	29.8	44813.06	31.0	29813.06	32.2	35163.73	35.2
Brunei		21.1		18.5		16.3		15.3		16.4	85637.71	17.4	102404.6	19.1	74525.74	20.3	60654.81	21.5	51049.88	21.7	60517.66	22.3	83200.98	24.0	81980.63	25.9	68632.53	28.9
Bulgaria		26.0		27.6		29.2		30.8	4545.79	31.8	6602.803	32.1	8413.145	32.9	10631.93	34.4	12042.44	35.5	10361.1	37.0	9956.198	38.6	13120.2	40.0	16649.31	40.8	17693.73	42.6
Burkina Faso		18.6		18.8	977.4672	18.7	962.8994	18.6	1025.234	17.9	1079.39	17.1	1221.381	16.5	1124.808	16.0	1117.451	15.4	1134.326	15.2	1452.542	15.4	1641.103	16.0	1634.335	16.0	1716.611	16.0
Burundi		18.3		17.3	754.9922	16.5	693.0626	16.4	853.2207	16.3	821.0557	16.0	976.7756	16.2	1009.594	15.6	1015.284	14.7	816.3983	14.4	747.8341	14.7	754.1615	15.7	766.5949	16.3	853.4425	15.6
Cambodia		17.5		17.2		16.8		16.8	1814.986	16.8	1117.994	16.4	894.6796	17.3	870.8439	17.2	1126.288	17.2	1448.863	16.9	1397.37	18.1	1984.006	20.0	2470.134	21.6	3481.186	24.2
Cameroon		19.4		19.8	1570.602	19.6	1748.848	18.9	1748.946	18.0	1766.685	17.1	2402.565	16.5	3536.363	15.9	2634.4	15.6	2426.949	15.6	2673.3	16.0	2795.196	16.4	2935.96	16.7	3367.544	17.1
Canada	12878.9	26.7	14329.36	26.3	15393.97	25.5	18586.87	24.5	21467.53	25.0	24733.97	26.4	28173.58	28.1	30560.17	30.0	34183.89	31.9	35738.74	33.8	41998.54	35.8	47073.38	37.6	45646.47	38.5	46945.5	39.6
Cape Verde		16.8		17.1	1257.746	17.9	1035.883	16.0	1710.937	15.8	1584.232	15.6	1821.405	15.3	2004.428	15.4	2351.278	15.3	2616.093	15.7	3989.516	17.1	4703.198	19.4	6556.297	21.3	6515.848	23.7
Cayman Islands		23.2		23.1		22.8		21.4	37095.66	20.2	42680.9	22.2	51621.28	25.1	55282.1	26.2	93746.13	28.5	76383.76	29.8	83431.4	32.1	84655.23	32.9		34.1	64717.41	35.4
Central African Rep		21.2		20.4	1550.246	19.5	1502.004	18.7	1565.022	18.0	1319.851	17.4	1139.772	17.1	1316.156	16.6	1208.382	16.2	1223.683	15.8	1038.014	15.8	952.6827	15.9	1120.837	15.7	872.6036	14.5
Chad		20.4		19.7	1442.258	19.1	1505.888	18.4	1402.889	17.5	1476.972	16.8	910.7886	15.6	1218.288	15.2	1196.39	15.2	1160.876	14.9	1031.267	14.6	1561.046	14.7	2135.632	14.6	1942.656	14.7
Chile		19.4	4876.614	19.5	5178.163	19.4	5764.074	19.3	6819.963	19.7	5618.435	20.6	7306.06	21.9	6258.402	23.3	8012.586	24.7	11898.53	26.2	11693.73	27.9	14570.87	29.9	20055.4	31.3	23214.65	33.3
China		22.2	1050.511	20.7	994.1747	19.9	1168.04	18.5	1292.507	18.0	1428.976	19.0	1678.258	20.8	2336.525	21.7	2427.055	23.7	3431.236	26.1	4199.84	28.9	6588.563	31.7	10116.53	33.7	12784.44	35.6
Colombia	3486.087	16.9	3977.213	16.2	3875.562	15.5	4134.597	15.2	4841.015	15.7	6681.997	16.7	7802.737	18.0	7189.221	19.4	7624.974	20.7	8597.688	21.8	7760.558	23.0	8529.045	24.5	11956.13	26.0	13796.84	28.5
Comoros		20.1		19.6	2043.115	18.8	3023.992	17.9	3496.081	16.6	3926.034	16.5	4266.281	16.3	4635.968	15.7	4056.267	15.5	3733.763	15.5	2951.087	15.7	3319.014	16.1	2503.141	17.2	2988.681	18.6
Congo		18.9		18.5	2057.5	17.9	2577.472	17.2	2988.263	16.6	3766.845	16.1	3852.466	15.9	5242.557	16.2	3021.775	16.5	2098.325	16.9	2908.707	17.3	4293.371	18.0	5782.818	18.5	4702.705	18.1
Costa Rica	3650.119	17.3	4893.433	16.8	5185.354	16.1	5652.585	15.9	6586.273	16.7	7449.155	18.1		19.5		20.9		22.0		23.1		24.5		26.2		27.7		30.2
Cote d'Ivoire		16.8		17.3		17.5		17.4		16.7		16.6		16.4		15.1		15.3		16.0		16.3		16.2		16.6		16.8
Croatia		26.7		27.1		28.2		29.8		31.4		32.4		32.5		33.4		34.8		36.8		37.9		39.3		40.6		42.2
Curacao		21.6		20.7		19.0		18.6		18.8		20.0		22.1		24.5		27.1		29.9		33.2		35.2		36.7		37.7
Cyprus		22.7		22.6		22.0		22.7		23.9		25.3		26.8		27.9	22535.14	28.9	23329.41	29.6	27567.72	30.6	28928.69	31.6	31855.75	32.6	28228.88	34.9
Czechia		31.3		31.3		32.1		32.8		32.5		31.6		31.9		33.1	24236.41	34.3	22479.89	35.3	22501.2	36.4	27212.76	37.8	30265.84	38.5	32746.5	40.3
Democratic Republ	2154.44	17.1	3067.096	17.2	2983.812	17.3	2736.689	17.5	2878.846	17.3	2274.278	16.8	2184.834	16.8	2143.602	16.6	1488.012	16.5	790.2629	16.8	544.6713	15.8	637.1298	15.7	712.1791	15.7	944.7918	15.7
Denmark	10533.17	30.7	11132.26	31.6	13568.79	32.1	16703.31	31.8	19875.74	31.5	20856.07	31.8	23979.72	33.3	24626	35.1	27817.98	36.1	30550.24	36.7	37403.96	37.3	43031.41	38.5	48860.06	39.4	47492.91	40.6
Djibouti		15.6		16.2		16.6		16.9	9147.143	16.8	8211.864	16.4	5107.33	16.3	4289.876	16.4	2821.979	16.8	3340.168	17.4	2903.895	19.0	3091.221	19.8	3053.968	20.6	4751.606	22.1
Dominica		17.4		17.0		16.7		15.6	4824.574	14.5	5801.033	16.1	6083.376	17.5	7370.264	20.1	9631.405	21.8	10189.95	24.0	9353.935	26.6	8052.147	28.6	10033.59	30.0	10134.62	30.4
Dominican Republi		15.9	2529.111	15.7	3234.121	14.8	2784.45	14.4	3103.181	14.7	4043.056	15.7	4097.773	16.8	5130.99	17.9	5110.102	19.0	6529.189	20.0	8391.977	21.3	9431.821	22.6	13096.97	23.7	15161.65	25.3
Ecuador	3364.039	19.0	4106.469	17.9	4364.315	17.0	4684.809	16.4	5207.834	16.5	7078.207	16.8	7915.238	17.5	7071.114	18.3	6184.488	19.3	5668.046	20.2	5510.876	21.1	7963.39	22.4	9908.478	23.5	11354.9	25.4
Egypt		19.6		19.6		18.7	945.2157	18.0	1233.07	18.1	1390.665	18.1	1503.488	18.1	2057.768	18.2	2363.026	18.4	4353.587	18.9	5409.204	20.0	6153.464	21.2	10419.65	22.2	12621.58	23.1
El Salvador	668.4138	17.2	715.8525	16.5	745.048	16.0	890.7802	15.7	949.9193	15.5	1071.175	15.8	1060.596	16.4	1032.434	17.0	1048.695	17.6	1621.595	18.5	2323.745	20.2	3658.762	21.7	6049.797	22.5	7584.579	24.0
Equatorial Guinea		22.5		21.5	1175.737	20.6	1458.73	19.8	1913.591	19.1	2856.571	18.7	2976.151	18.0	2727.949	18.7	2488.554	18.5	2145.975	18.0	10087.06	17.9	27228.81	18.2	38225.53	19.2	27242.69	20.5
Estonia		28.9		28.8		31.1		32.1		32.7		33.4		32.7		32.9	12396.85	33.3	10758.37	35.3	13010.5	37.0	20291.97	38.3	23852.14	39.0	28516.85	40.6
Eswatini		17.3		16.3		15.3		14.8	2391.762	14.9	3812.58	14.6	3907.649	14.3	4335.37	14.2	6759.976	14.9	8668.011	15.0	8695.067	16.2	8902.012	17.3	8761.442	18.2	8732.563	19.8
Ethiopia	425.4608	16.9	504.3441	17.1	536.4225	17.3	613.4501	17.4	652.3857	17.1	673.3656	16.4	728.3732	16.0	961.0323	16.0	821.5864	15.7	651.8162	15.3	593.4034	15.1	806.1251	15.4	1155.479	15.9	1758.566	17.2
Fiji		16.7		15.6	3122.213	15.1	3134.865	15.2	4229.561	15.8	5309.5	17.0	6420.871	18.1	5376.116	19.0	6942.425	19.6	6433.89	19.9	6694.667	21.1	5941.677	22.6	8670.004	23.8	12973.97	25.3
Finland	6581.006	26.7	8529.524	26.9	9945.215	27.4	11993.56	27.6	15758.58	28.6	18063.59	29.6	21286.98	31.8	22419.22	33.7	27493.33	35.5	28161	36.9	35949.78	38.4	40534.97	39.9	43468.39	40.9	41660.52	41.5
France	7635.002	33.5	9215.029	32.0	11134.62	32.0	13855.95	32.0	17435.08	31.6	20989.45	30.8	24980.37	31.4	22841.9	32.7	27149.92	34.0	28275.72	35.4	34969	36.8	37604.82	38.0	39900.06	38.9	40998.42	40.4
Gabon		27.1		26.8	3861.646	26.1	6641.612	24.9	8101.081	23.1	12716.69	21.4	14617.96	19.9	12808.57	18.6	11923.69	17.8	10694.77	17.7	11433.37	18.2	17984.84	19.0	13814.35	19.9	15222.64	21.1
Gambia		17.0		17.9	2815.832	18.4	2995.769	18.7	3099.849	18.5	3319.183	17.8	2889.372	16.9	3144.045	16.4	2878.571	16.2	2729.706	16.0	2913.825	15.9	3571.454	15.9	2956.557	15.9	2270.708	16.1
Georgia		24.9		26.0		26.6		27.4		27.7		27.1		27.8		28.6	11769.19	29.8	2719.635	31.1	3831.306	32.4	6093.007	33.5	8912.809	34.4	12695.08	36.0
Germany	5227.417	33.4	8258.347	33.5	11158.83	33.7	13321.44	33.4	15778.72	33.1	18229.62	34.4	22038.22	35.8	21471.29	35.9	28100.42	36.4	32570.66	37.4	37290.41	39.0	41565.6	41.2	45435.34	42.8	48064.57	44.7
Ghana		17.7	3869.317	17.9	4536.673	16.9	4470.426	15.7	4524.156	15.3	3964.355	15.4	3524.42	15.9	2842.324	15.8	2928.985	15.4	2818.973	16.0	3467.583	17.1	3346.965	18.3	4363.856	19.1	5354.642	19.7
Greece		24.6	4389.173	26.0	5481.608	27.9	8015.466	30.6	11460.88	32.9	13942.77	33.9	15780.88	33.7	15503.57	34.2	17753.79	35.0	20419.39	36.0	25357.28	37.3	29086.72	38.8	29795.95	40.2	26330.74	42.4
Grenada		15.1		16.0		15.1		14.7	2235.318	15.0	3172.152	17.0	3980.395	18.3	3942.925	19.8	5515.685	20.8	6780.047	21.8	7914.278	23.1	9267.035	24.6	10547.42	26.2	13115.29	28.5
Guatemala	2285.435	16.8	2162.752	16.4	2376.898	15.7	2551.452	15.7	3052.106	15.8	3457.578	15.8	4045.083	15.9	3610.553	15.8	4007.872	16.0	4710.435	16.3	5402.275	16.7	6019.335	17.5	6941.245	18.5	7737.959	20.1
Guinea		20.7		20.3	3415.742	19.9	3446.148	19.5	3003.918	19.0	3303.935	18.5	3471.921	17.8	3331.386	17.4	3456.247	17.2	3596.579	16.9	2790.32	16.3	1972.349	15.9	2021.206	16.2	2086.237	16.9
Guinea-Bissau		20.4		21.0		21.5		18.9		17.6	1487.05	17.5	1446.381	16.5	1177.161	15.6	1698.165	15.3	1693.824	15.7	1771.99	16.2	1645.127	16.7	1487.183	16.9	1665.397	17.3
Guyana		18.6		17.0		15.4		14.9	3825.277	15.0	4570.508	15.7	4304.212	17.0	3258.88	18.7	3122.467	20.0	3941.625	20.7	4687.493	21.2	7447.572	22.0	9053.243	22.8	11144.11	23.9
Haiti		19.0		18.8	1479.29	18.8	1372.012	18.7	1357.652	18.4	1555.968	18.5	1954.637	18.4	1618.949	18.2	1491.065	17.8	1469.204	17.8	2175.768	18.3	1898.385	19.2	1826.826	20.1	1913.09	21.6
Honduras	2339.028	17.6	2122.294	16.7	2242.816	15.6	2423.135	14.9	2442.147	14.9	2474.447	14.9	3063.854	15.1	2851.46	15.3	3253.694	15.6	3764.519	16.2	3541.543	17.1	4056.442	18.2	4111.901	19.3	4976.486	21.3
Hong Kong		22.8		22.8	6004.625	22.0	8302.59	19.2	10478.25	20.2	13086.18	22.2	19482.24	24.5	21794.01	27.0	32684.73	29.8	40662.21	32.6	44197.27	35.1	60869.18	37.8	55370.08	39.6	51588.31	41.9
Hungary		29.1		29.8		31.1		32.5	5978.889	33.1	7410.244	33.3	11746.49	33.3	12054.41	34.1	14206.8	35.3	14655.2	36.7	16553.89	37.5	21192.76	37.9	23814.27	38.7	25278.67	40.7
Iceland	9509.539	25.5	12095.2	25.1	12724.49	24.4	17447.12	23.1	17612	23.4	23470.52	24.4	29624.11	25.9	29867.03	27.3	33947.12	29.0	33038.73	30.4	39474.6	31.9	45611.08	33.2	43342.04	33.6	47414.69	35.0
India	950.7153	20.0	1049.534	19.7	1168.072	19.2	1271.174	18.5	1434.17	18.3	1593.608	18.6	1310.529	19.0	1184.801	19.5	1430.103	20.0	1702.782	20.7	2137.655	21.6	2973.66	22.6	4554.742	23.7	5634.441	25.5
Indonesia		17.8		18.8	1387.893	19.1	1406.217	18.7	1313.445	17.9	1803.573	17.9	2408.41	18.4	2729.85	19.4	3436.34	20.7	4604.463	22.2	3753.768	23.7	4452.749	25.3	8177.112	26.4	10247.41	28.0
Iran		20.6	2680.679	19.8	4052.06	18.3	5176.021	16.9	7584.32	16.8	9089.758	17.2	4104.133	17.2	3398.519	17.1	3292.606	17.3	5455.544	18.1	8242.715	20.7	14921.05	23.6	19116.52	25.9	13497.84	28.9
Iraq		20.5		19.6		19.6		18.4	4715.712	17.1	7730.698	16.0	9622.123	15.4	6724.95	15.7	7201.835	16.1		16.6	7589.315	17.0	6618.354	17.5	13105.48	17.8	10494.44	18.6
Ireland	5439.048	29.1	6157.824	29.3	6697.145	29.2	7732.919	27.7	9313.152	26.1	10943.16	25.6	14065	25.5	13992.83	26.3	19040.83	28.3	25668.75	29.9	39746.35	31.5	55875.63	32.4	52986.94	32.8	75990.27	35.4
Israel	5786.685	24.6	7367.253	24.8	9298.083	24.5	11298.2	23.4	15009.86	22.6	18721.4	23.1	18795.83	24.0	20157.39	24.7	23651.15	25.3	28639.36	26.0	35327.11	26.7	31816.09	27.7	32680.99	28.3	37281.35	28.8
Italy	4536.186	27.5	5900.365	29.2	7582.857	30.5	9266.725	31.3	13036.21	32.0	15623.42	32.6	21941.05	33.1	21268.63	34.6	27016.47	36.1	30583.93	37.7	36099.54	39.2	36438.45	40.8	38651.53	42.1	36995.26	44.4
Jamaica		21.1	4327.694	20.9	5523.095	18.6	6344.891	17.4	7165.098	16.2	7310.404	16.7	4754.877	18.0	3884.63	19.2	5283.718	20.5	5687.16	21.3	5864.073	22.1	6879.631	23.5	7533.597	25.0	8088.889	27.8

Japan	2804.927	21.2	3785.076	22.8	5473.627	24.8	8102.635	26.6	13023.33	28.2	15796.56	29.8	20852.17	31.6	20254.34	34.5	29385.46	36.9	35783.74	39.0	37915.27	40.7	39823.62	42.4	39789.7	43.9	40274.21	45.9
Jordan		17.1	1838.889	16.8	3028.679	16.1	4015.686	14.8	3103.52	13.9	2484.255	13.8	4253.421	14.1	4214.268	14.8	3835.925	15.7	3672.923	18.0	3860.021	18.6	6394.599	19.4	10614.14	20.2	10457.68	21.4
Kazakhstan		22.0		22.5		22.1		22.4		21.2		21.8		22.6		23.7	12296.98	24.7	6327.203	25.2	6245.465	26.7	11327.53	27.7	20422.45	28.0	23783.73	28.6
Kenya	1643.981	16.0	1743.913	15.7	1738.998	14.6	1873.945	13.9	1792.743	13.3	2067.45	13.1	2226.308	13.3	2245.778	13.8	2314.923	14.3	2319.676	14.9	2150.216	15.6	2093.725	16.4	2608.519	16.9	3538.228	17.9
Kuwait		20.3		20.9		21.0		19.2	141652.2	17.1	82249.57	16.7	64392.37	18.6	37271.21	20.4	22365.75	20.8	48900.95	24.9	44734.07	25.1	77999.84	27.4	77888.24	28.2	54531.47	32.9
Kyrgyzstan		23.6		23.4		22.2		20.3		19.1		19.2		19.6		20.4		20.5	3458.234	20.0	2277.892	20.9	2550.532	21.8	3658.164	22.4	4853.494	23.1
Laos		18.8		18.4		18.1		17.7	774.5477	17.5	890.4529	17.4	914.1924	16.7	1183.614	16.7	1411.615	16.7	1639.961	16.8	1969.959	17.3	2778.299	18.4	4470.572	19.8	6627.723	22.0
Latvia		29.2		29.9		31.2		32.3		33.0		33.9		33.8		33.5	16812.02	33.7	9602.492	34.9	11853.22	37.0	16700.62	38.9	19327.38	40.0	24716.61	42.1
Lebanon		22.0		20.8		19.1		17.2	7580.319	17.3	6054.439	18.2	6439.457	18.9	9172.637	19.7	4827.023	20.5	4252.134	21.7	5547.002	23.2	13152.83	25.0	17581.87	26.7	15271.16	28.8
Lesotho		17.7		16.6	1021.43	16.3	1330.462	16.3	1434.748	16.9	1935.298	17.7	2064.516	17.5	2020.21	17.2	2404.634	17.4	2548.2	17.7	2454.026	18.5	2771.748	19.1	2692.544	19.8	3382.441	21.0
Liberia		17.9		18.3		18.4	1788.853	18.5	2103.219	17.9	2122.315	17.4	2122.761	16.6	1503.409	16.3	906.8702	16.7	271.8384	17.1	995.2094	17.5	1106.631	17.5	879.0945	17.4	1210.175	17.5
Lithuania		25.1		25.7		26.8		28.3		29.6		30.5		30.7		31.0	14695.23	31.6	9495.179	33.0	12111.56	35.1	17388.69	37.6	20978.11	39.5	27162.24	42.1
Luxembourg	14919.36	33.9	15821.89	33.9	18467.48	34.1	18992.67	34.2	23633.42	34.4	24126.01	34.0	28116.15	33.9	26308.79	34.8	38945.75	35.3	46934.92	35.6	66585.98	36.2	66100.27	37.2	67784.19	37.8	82382.44	38.3
Macao		24.4		23.4		20.8		16.8	6361.435	17.6	10514.42	21.2	14934.29	24.3	17246.93	26.0	25753.53	27.4	35288.61	29.7	31524.32	31.9	50222.13	33.4	104660.1	34.7	99116.41	36.0
Madagascar		19.7		18.5	1609.179	17.0	1596.86	15.6	1870.481	15.5	1618.312	15.3	1546.641	15.3	1494.599	15.5	1423.896	15.9	1174.533	16.2	1269.455	16.3	1391.348	16.5	1652.353	16.9	1643.513	17.9
Malawi		16.1	803.721	16.8	899.3621	17.2	976.609	17.4	1146.986	17.1	1370.73	16.5	1267.751	16.3	1544.495	16.0	1061.91	15.9	1154.66	15.7	954.1786	16.0	1200.087	15.9	1159.487	15.6	1124.051	15.7
Malaysia		18.8	2431.762	17.3	2690.403	16.2	3416.876	15.6	3883.338	16.2	5483.553	17.3	7404.997	18.6	7855.67	19.8	9329.916	21.0	12752.09	21.9	13385.83	22.9	16883.43	23.4	19924.39	24.6	23256.72	27.3
Maldives		17.4		18.7		19.4		18.7	2993.018	16.3	2633.278	16.0	3825.085	15.8	4581.963	16.0	7194.987	15.5	7262.843	15.8	9386.698	17.8	13147.6	20.4	14370.84	22.8	18039.45	26.8
Mali		19.4		19.1	776.5978	18.7	601.8163	18.6	660.0756	18.3	616.8556	17.8	713.9233	17.0	1003.879	16.2	749.7677	15.4	973.892	15.2	1380.947	15.4	1467.487	15.5	2017.812	15.4	1987.023	14.8
Malta		23.7		22.1		21.9	2114.258	23.0	3527.57	25.3	6389.51	27.4	11051.61	29.2	12688.6	30.6	15090.89	32.2	17098.65	34.1	25529.68	35.8	25560.51	37.7	26953.38	39.0	33804.83	39.2
Mauritania		16.7		17.0	2018.135	17.1	3174.211	17.0	4019.988	16.4	4420.023	15.9	3907.953	15.8	3369.352	15.9	3229.04	16.1	3361.778	16.6	3186.704	16.6	3666.465	16.8	4468.001	17.0	4392.759	16.9
Mauritius	5205.505	17.9	4806.773	16.7	4113.979	16.0	4850.342	16.2	4868.264	17.3	5306.13	19.1	6689.592	20.7	7834.695	22.4	11846.35	24.6	14867.98	26.3	16539.1	27.9	15024.49	29.5	17088.41	31.1	20134.16	34.1
Mexico	5064.555	16.9	5857.645	16.1	6676.689	15.6	7951.686	15.2	9180.868	15.1	10928.39	15.6	14127.02	16.3	13072.4	17.4	12382.7	18.7	12184.5	20.3	14849.22	21.8	15638.17	23.3	16873.34	24.6	18518.39	26.7
Moldova		25.4		24.3		23.7		24.7		26.0		26.0		27.5		28.5	6324.963	29.7	3406.426	31.0	2596.441	31.6	3973.43	32.0	5130.034	32.9	7468.925	34.7
Mongolia		23.8		22.4		21.7		19.3	1378.671	16.4	1553.931	16.0	1948.115	16.6	2420.227	17.4	3805.836	17.9	2816.204	19.0	3213.199	20.7	5646.207	22.7	8756.164	24.1	10785.08	25.8
Montenegro		20.7		20.9		21.7		22.5		22.5		24.1		25.7		27.2	11984.59	28.7	5978.092	30.5	8886.786	32.2	10241.37	33.6	16865.26	34.9	18007.46	36.5
Montserrat		17.6		17.0		17.4		18.9	14778.21	19.4	17313.79	21.0	20961.88	23.2	24655.14	25.1	44466.91	27.1	28653.97	30.7	25091.53	35.3	25767.91	37.0	22261.4	37.4	15236.81	38.5
Morocco	1387.264	18.3	1390.505	17.8	1398.92	16.5	2220.668	15.4	2208.955	15.4	2546.613	15.9	2952.831	16.5	3815.482	17.2	4546.292	18.2	5263.442	19.6	4984.969	21.3	4880.08	23.0	6897.943	24.5	7604.144	26.6
Mozambique		19.1		18.6		18.3		17.7		17.0		16.6		16.3		16.3	714.2318	16.5	706.4072	16.8	857.1803	16.6	1190.014	16.3	1227.096	16.1	1343.997	16.2
Myanmar		20.7		20.6		19.9	806.8197	18.9	760.6832	18.4	747.044	18.6	856.5897	19.0	963.7565	19.5	762.569	20.5	1044.479	21.6	1123.416	22.9	1804.991	24.2	3679.634	25.4	4774.133	27.3
Namibia		19.8		18.7	4204.314	17.6	5287.985	17.1	5855.509	16.8	6175.523	16.4	6340.826	15.4	5944.221	15.5	5062.877	17.2	5657.326	17.6	6176.453	17.9	7330.709	18.4	8970.764	19.1	11041.7	20.4
Nepal		18.6		18.5	761.8359	18.4	791.2252	18.5	846.0715	18.5	810.8852	18.6	804.2745	18.4	979.3983	18.3	1137.866	18.1	1528.819	18.2	1485.46	18.4	1422.826	19.1	2118.272	19.9	2829.85	21.5
Netherlands	9007.362	27.0	11280.05	27.6	13113.14	27.8	15301.05	27.6	19090.38	27.5	23108.59	28.4	26173.99	30.4	24075.87	32.1	28432.92	33.5	32155.63	34.9	42616.64	36.4	48942.48	38.1	50553.6	39.5	51664.72	41.2
New Zealand	11963.81	28.4	12163.17	27.8	14358.21	26.5	16518.58	24.9	16909.85	24.6	18867.78	25.3	18241.32	26.9	19984.46	28.4	23036.62	30.1	25871.38	31.6	29589.34	33.3	31823.97	34.5	34903.13	35.7	37060.95	36.3
Nicaragua	3635.648	16.5	5091.794	15.7	4851.699	15.0	6964.356	14.7	7060.569	14.9	7457.798	15.0	5681.732	15.0	5565.932	15.1	3537.748	15.6	3521.382	16.6	4033.304	18.0	4306.813	19.5	4466.515	20.6	5300.763	22.5
Niger		14.2		14.3	2008.355	14.5	2383.346	14.4	2124.346	14.6	1598.72	15.0	1954.884	15.2	1345.55	15.2	1210.162	15.3	1123.647	15.4	1036.89	15.3	1036.271	14.8	1190.572	14.5	1191.828	14.4
Nigeria	1799.922	18.1	1834.39	18.3	2001.772	18.3	2284.254	18.3	2900.253	18.0	4040.223	17.5	4807.376	17.0		16.5		16.4		16.7	941.4752	17.0	3456.341	17.0	5035.759	16.8	5576.293	16.7
North Macedonia		20.1		20.7		21.2		21.2		22.1		23.8		25.5		27.4	6535.023	29.7	6264.312	31.1	8013.895	32.0	9492.968	32.9	12668.96	34.2	14449.23	36.1
Norway	9826.614	31.4	11486.55	32.6	12448.91	33.4	14929.27	33.1	13790.82	31.8	19913.45	31.2	27764.76	32.4	30526.92	33.6	32764.59	34.4	37309.2	35.1	56381.22	35.8	76282.56	36.9	83524.73	37.6	70778.65	38.2
Oman		17.8		18.0		18.0		17.6		16.3	9185.331	15.5	13303.52	15.5	16705.21	15.4	13676.45	17.1	12821.03	18.8	19674.73	19.6	32524.39	21.4	47959.4	23.6	35037.95	27.8
Pakistan	1381.48	18.7	1273.91	18.6	1308.878	18.4	1605.902	18.0	1972.851	17.2	2036.954	16.8	2266.496	17.2	2563.723	17.4	2764.075	17.1	2844.11	16.7	2879.38	17.2	3334.083	17.9	4204.377	18.6	4649.528	19.4
Palestine		16.1		15.6		15.1		14.6	1388.902	14.3	1927.647	13.8	2653.017	13.9	2258.456	14.1	2615.589	14.3	3455.62	14.4	3609.345	15.0	3893.771	15.8	4354.984	16.8	6230.221	18.3
Panama	2169.879	17.7	2494.985	17.2	2888.155	16.8	3733.234	16.6	5322.848	16.6	6188.139	17.1	6774.934	18.1	6655.569	19.2	6951.892	20.5	7965.124	21.9	10030.54	23.3	13825.34	24.6	16334.6	25.7	24786.47	27.2
Paraguay		15.9	2361.174	15.4	2345.648	15.4	2546.885	15.5	2833.687	15.8	3320.358	16.6	4648.966	17.5	4671.192	18.0	5233.199	18.3	5732.649	18.5	5208.982	19.1	7434.926	20.4	10500.25	21.7	11727.36	23.7
Peru	2250.394	17.9	2666.491	17.6	2903.336	17.1	3522.477	16.7	3822.321	16.8	4512.575	17.0	4275.365	17.4	4007.126	18.0	3700.613	18.8	5024.656	20.0	5241.155	21.5	6727.838	23.1	10113.22	24.6	11662.25	26.7
Philippines	1477.582	16.8	1855.735	15.5	2024.011	14.8	2226.519	14.8	2449.746	15.3	3032.175	16.2	3493.874	17.2	3008.201	17.7	4103.079	18.4	5121.713	19.1	4540.943	20.0	4605.261	20.8	5814.083	21.6	7088.78	23.0
Poland		24.8		25.1		25.6		26.5	5783.331	27.3	7389.159	27.4	6928.258	28.5	7977.029	29.8	8554.509	31.5	11685.22	33.0	15115.9	34.3	17152.69	35.6	23428.09	36.7	27173.2	38.7
Portugal	2978.414	25.0	3813.143	26.2	4576.537	26.9	6021.004	27.9	8419.91	28.6	9862.736	28.8	11608.85	29.6	10834.54	31.1	15835.44	33.2	19151.79	35.1	24812.99	36.7	26620.92	38.5	28848.96	40.1	28654.19	42.8
Qatar		17.6		16.7		17.0		21.5	104477.3	22.6	109050.9	19.8	90604.88	22.4	38127.46	26.0	35855.13	26.7	30754.37	28.1	65698.72	28.8	117865.9	29.6	137985.2	29.3	108237.4	30.2
Romania		25.2		26.0	1517.148	27.3	2234.936	29.0	3001.795	30.8	4825.748	31.0	6856.425	30.6	7819.785	31.3	8187.848	31.9	8441.648	33.0	8579.492	33.6	11938.75	35.8	18466.55	37.8	21573.5	39.9
Russia		23.4		24.8		26.3		27.4		29.7		29.9		30.1		31.0	16903.91	32.2	10408.82	33.9	9876.465	35.6	15078.19	36.4	24175.52	36.8	25285.74	37.6
Rwanda		17.2		16.5	1039.691	14.9	861.2242	14.2	1102.464	14.9	1068.202	15.4	1282.195	15.5	1255.931	15.0	1125.25	14.6	681.249	13.6	958.9727	15.4	1308.727	16.8	1625.853	17.5	2016.811	18.2
Saint Kitts and Nev		21.2		16.9		15.8		15.4	4448.131	14.9	5672.932	17.2	8354.716	18.9	9234.757	21.0	12730.1	22.3	13815.26	23.7	18561.99	25.6	18998.79	27.5	20369.27	29.0	20730.39	31.4
Saint Lucia		18.5		17.3		15.8		14.6	5091.628	14.2	5305.014	15.2	8297.7	16.1	8374.498	17.3	10136.09	18.6	9680.396	20.8	9474.905	23.3	10708.13	26.0	11019.9	28.2	12314.02	30.6
Saint Vincent and t		18.1		15.6		14.4		13.9	4142.053	14.3	3734.566	15.2	4820.038	16.6	5398.351	18.4	6639.186	19.5	8078.1	21.0	8712.663	23.0	8692.937	25.3	10196.74	27.4	10784.74	30.7
Sao Tome and Prin		23.7		22.9		23.2		19.8	2309.819	15.7	2631.672	16.0	2958.262	16.2	2295.443	16.1	1957.627	16.0	1610.542	15.9	1974.415	16.7	2784.527	17.4	3148.094	17.7	4367.929	17.7
Saudi Arabia		17.9		17.3		16.5		16.1	24353.06	16.2	39572.96	16.6	42575.98	16.2	19838.76	17.0	18845.42	18.2	19581.18	19.3	22472.92	21.2	32061.6	23.2	50698.19	24.7	53927.86	28.3
Senegal		18.0		17.7	2868.133	17.3	2651.514	17.0	2422.086	16.9	2370.606	16.8	2315.469	15.9	2973.07	15.3	2876.114	15.5	2543.297	16.0	2781.177	16.4	2919.781	16.9	3103.989	17.1	3069.638	17.2
Serbia		24.5		25.5		26.5		28.6		30.4		31.8		32.6		34.1	12205.64	35.7	5582.178	37.2	8301.854	38.6	10908.84	39.7	14880.15	40.6	15407.8	41.7
Seychelles		26.1		23.0	6555.886	20.8	6856.069	19.1	8990.584	17.3	16424.45	17.4	16904.91	18.7	14503.63	20.3	19622.15	22.2	20380.89	23.9	23785.51	25.2	21149.34	27.3	20765.44	28.9	23875.11	30.8
Sierra Leone		19.4		19.9		19.9	1087.418	19.7	1380.491	19.1	1397.033	18.4	1240.876	17.9	1329.512	17.6	1577.229	17.3	1858.424	17.1	1039.898	16.9	1110.48	16.9	1263.568	17.0	1836.82	17.7
Singapore		18.9		18.0	2764.531	16.8	4186.449	16.5	7215.832	18.5	11644.38	20.8	19827.23	23.5	20812.95	26.2	28637.94	28.3	22475.36	31.3	40524.95	33.7	62080.61	35.3	71970	36.4	75352.24	38.7
Sint Maarten (Dutc		26.8		21.1		18.8		18.4		19.8		21.3		23.5		24.1		26.6		29.0		30.5	34814.36	32.4	38139.24	33.8	24893.52	42.0
Slovakia		26.0		26.4		26.7		26.9		27.2		27.2		27.9		29.0	19718.28	30.3	15759.5	31.4	16586.26	32.9	20581.33	34.5	27152.83	35.8	27625.57	38.2
Slovenia		26.0		26.6		27.9		29.1		29.8		30.3		30.4		31.5	20033.02	33.0	21183.34	34.8	23822.06	36.8	28253.65	38.7	29828.68	40.0	29830.53	41.6
South Africa	5967.939	19.2	6408.547	18.5	6773.041	17.7	7941.853	17.7	9138.158	17.8	9941.979	18.3	10303.7	19.2	9783.802	18.8	9511.48	20.0	9211.527	20.4	9835.729	20.9	11681.9	22.3	12896.75	23.3	12932.48	25.3
South Korea		17.6	1211.233	17.6	1256.048	17.9	1499.817	17.4	2210.794	17.6	4501.716	18.8	5414.487	20.9	7476.701	23.2	13819.28	25.8	22422.61	28.3	24834.43	30.7	32088.42	33.6	35927.84	36.0	38249.12	39.9
Spain	3857.872	26.5	5236.101	27.7	6368.107	28.4	9079.128	29.2	11811.08	29.2	14332.13	29.1	16096.19	29.8	13693.12	30.9	18580.34	32.6	21821.61	34.4	28207.71	36.4	32439.23	37.7	34567.6	38.7	35774.75	41.5
Sri Lanka	2800.744	20.3	2976.944	19.2	2969.983	18.4	2821.499	18.3	3309.185	18.8	3363.085	19.6	2563.672	20.5	2870.128	21.6	3358.006	23.2	4203.322	24.8	4912.573	26.4	5823.609	27.8	9202.438	28.9	12045.04	30.8
Sudan		16.1		16.0		15.7		15.4	1785.844	15.1	2170.983	15.0	2312.796	15.3	1986.204	15.3	2031.909	15.0	1881.772	15.1	2265.119	16.0	2909.719	16.8	4088.665	17.5	4144.497	17.7
Suriname		18.1		16.8		15.8		15.2	4909.377	14.5	5723.411	15.9	6521.918	17.3	7061.999	18.9	7023.921	20.1	6022.854	21.2	7505.624	23.2	9935.095	24.7	13323.82	25.4	14760.16	26.8
Sweden	10465.07	33.2	11804.64	34.1	13470.28	35.1	16803.1	35.2	19770.75	34.5	21933.44	34.2	22666.73	35.1	25541.88	36.6	30300.88	37.4	31846.59	37.7	39777.26	38.3	42820.68	39.2	46317.09	39.7	50104.22	39.8
Switzerland	16251.65	32.2	19953.74	31.9	23249.11	31.6	27104.67	30.5	31793.94	30.9	31364.01	32.0	35278.71	33.8	35892.36	35.1	42263.76	35.9	42405.1	36.3	47393.05	37.6	52752	39.2	64724.32	40.3	71452.91	41.2
Syria		19.6		18.3	2598.178	16.6	3331.959	15.5	3591.202	14.9	5675.671	14.6	2561.863	14.4	1957.272	14.7	1464.131	15.4		16.6	1739.534	17.8	5889.39	19.0	6208.395	20.6	5714.92	18.3
Taiwan		17.7	2102.336	17.1	2606.638	16.5	3663.033	16.5	5360.204	17.5	7640.286	19.4	11882.25	21.5	14179.15	23.7	22476.16	26.2	28481.73	28.5	35558.93	30.7	40211.39	33.0	41677.9	35.0	44206.37	38.1
Tajikistan		20.8		21.3		20.7		17.3		16.2		16.5		17.2		17.4		17.2	1975.953	16.4	1260.751	17.2	2066.249	18.5	3048.614	19.6	3297.684	20.6
Tanzania		16.0		16.1	1161.469	16.0	1419.297	16.0	1676.885	15.8	1899.053	15.8	1739.413	15.5	1716.843	15.2	1094.829	15.6	923.0513	15.9	1186.737	16.3	1594.942	16.4	2284.536	16.4	2468.433	16.4
Thailand	1219.25	17.5	937.4587	17.4	1205.706	17.0	1501.5	16.3	2486.442	16.4	2836.44	17.3	3736.908	18.9	4299.156	20.9	5926.176	23.3	8935.833	26.9	7754.838	30.1	10626.44	32.3	13892.67	34.0	15575.2	36.5
Togo		18.2		17.6	1238.234	17.0	1723.808	16.7	1966.118	16.5	2012.831	16.2	2424.612	15.9	1652.177	15.9	1899.938	16.1	1481.604	16.6	1490.213	17.2	1338.237	17.5	1297.448	17.8	1937.671	18.1
Trinidad and Tobag	6108.856	19.8	7776.792	17.9	10928.02	17.1	13286.25	17.1	16608.75	17.8	17550.48	19.3	23506.06	20.6	18251.22	21.8	12189.12	23.1	10363.36	24.5	14600.52	26.3	24625.36	28.2	31893.31	29.9	29230.36	32.7
Tunisia		19.1		18.1	1871.893	17.1	2083.908	16.4	2886.946	15.9	3968.596	16.4	4946.635	17.3	5510.495	18.4	6227.778	19.6	8370.447	21.2	9209.732	23.3	9700.734	25.7	12024.07	27.4	10798.31	29.6
Turkey	3408.929	18.6	4608.88	18.7	5130.868	18.4	5695.85	17.9	7211.26	17.2	9154.864	18.1	8409.397	18.6	9774.484	19.5	11445.99	20.8	11844.7	22.2	13102.52	23.6	14305.22	25.3	19774.95	26.8	25759.3	28.8
Turkmenistan		22.4		22.1		21.1		18.0		16.7		17.1		17.9		18.6		18.7		19.3	8034.441	20.2	10112.43	21.6	18016.64	22.8	22386.38	24.4
Uganda	909.6594	18.1	848.5218	17.2	867.9749	15.9	877.7247	15.3	1105.507	15.4	1118.368	15.0	828.0685	14.8	870.1943	14.8	896.452	14.7	1148.789	14.3	1280.732	13.8	1521.991	13.8	1946.539	14.0	1986.387	14.6
Ukraine		26.4		27.3		28.3		29.1		31.3		33.1		32.6		33.2	11947.13	34.0	5923.279	35.1	4870.476	36.8	7998.706	37.9	9614.152	38.2	10390.1	39.1
United Arab Emirat		17.5		16.7		18.3		20.3		21.3		24.3		25.2		25.6	144841.4	24.8	100359.4	26.9	111000	26.1	109441.8	27.8	72385.52	25.8	74834.68	29.2
United Kingdom	10457.38	33.9	12021.09	34.1	13277.79	34.5	15018.67	34.0	16703.92	33.2	17617.3	32.8	22179.24	33.3	22813.94	34.3	25300.64	34.8	28073.4	35.5	35217.96	36.6	39429.31	37.7	39109.24	38.3	42629.23	39.0
United States	15911.84	29.3	18205.36	29.2	19079.53	28.6	22745.73	27.5	25444.53	27.2	27739.98	27.9	31852.34	29.1	35481.77	30.4	39577.02	31.8	42847.79	33.1	50036.99	34.2	53969.16	35.1	53887.07	35.9	58543.56	36.6
Uruguay	6526.411	26.8	8123.412	27.4	7470.18	28.0	7337.606	28.4	8187.696	28.9	8600.181	29.0	10248.94	29.0	7954.665	29.3	9663.799	29.7	12355.19	30.3	11817.27	30.9	11229.85	31.8	17710.6	32.7	20543.25	34.0
Uzbekistan		22.7		22.5		20.9		17.3		16.6		17.1		17.9		18.6	6269.01	18.8	4504.666	19.1	4446.141	20.2		21.8	7567.727	23.1	10492.51	25.1
Venezuela	6121.138	16.1	7615.577	16.0	7649.257	15.5	8758.559	15.4	10262.23	15.8	12000.63	16.7	11883.76	17.8	9539.935	18.8	8492.927	19.8	8252.089	20.9	8666.309	22.1	11884.34	23.4	18995.25	24.5		26.2
Vietnam		23.1		22.1		20.3		17.9		17.4		17.7		18.7	1239.103	19.3	1253.219	19.8	1796.895	20.9	2331.679	22.9	3385.113	25.4	4761.238	27.3	6180.358	29.7
Yemen		18.2		18.3		18.4		18.1		17.3		16.1		14.9		14.0	818.9454	13.6	793.7806	13.6	1403.381	14.2	3664.496	15.2	4891.912	16.2	2533.911	17.6
Zambia		16.4	1341.641	16.3	1838.129	15.8	2321.02	15.3	2275.08	14.8	2365.538	14.2	1598.362	14.0	1977.921	14.3	1340.167	14.5	1021.174	14.5	1292.35	14.6	1776.487	15.0	3307.825	15.4	3277.054	16.0
Zimbabwe		17.4	1978.894	16.2	2448.017	15.3	2415.837	14.5	2893.595	14.6	3331.346	14.5	3119.952	14.1	4068.496	14.5	5299.885	14.8	5814.683	15.6	3356.706	16.8	1801.478	17.3	2281.992	17.2	2880.906	17.0

East Asia:	China, Hong Kong, Japan, Macao, Mongolia, South Korea and Taiwan
Europe:	Albania, Armenia, Austria, Belarus, Belgium, Bosnia and Herzegovina, Bulgaria, Croatia, Cyprus, Czechia, Denmark, Estonia, Finland, France, Georgia, Germany, Greece, Hungary, Iceland, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Moldova, Montenegro, Netherlands, North Macedonia, Norway, Poland, Portugal, Romania, Russia, Serbia, Slovakia, Slovenia, Spain, Sweden, Switzerland, Ukraine and United Kingdom
North Africa:	Algeria, Egypt, Morocco and Tunisia
North America:	Anguilla, Antigua and Barbuda, Aruba, Bahamas, Barbados, Canada, Cayman Islands, Costa Rica, Curacao, Dominica, Dominican Republic, El Salvador, Grenada, Guatemala, Haiti, Honduras, Jamaica, Mexico, Montserrat, Nicaragua, Panama, Saint Kitts and Nevis, Saint Lucia, Saint Vincent and the Grenadines, Sint Maarten (Dutch part), Trinidad and Tobago and United States
Oceania:	Australia, Fiji and New Zealand
South America:	Argentina, Belize, Bermuda, Bolivia, Brazil, British Virgin Islands, Chile, Colombia, Ecuador, Guinea, Guyana, Paraguay, Peru, Suriname, Uruguay and Venezuela
South Asia:	Bangladesh, Bhutan, Brunei, India, Maldives, Nepal, Pakistan and Sri Lanka
Southeast Asia:	Cambodia, Indonesia, Laos, Malaysia, Myanmar, Philippines, Singapore, Thailand and Vietnam
Sub-Sahara Africa:	Angola, Benin, Botswana, Burkina Faso, Burundi, Cameroon, Cape Verde, Central African Republic, Chad, Comoros, Congo, Cote d'Ivoire, Democratic Republic of Congo, Djibouti, Egypt, Equatorial Guinea, Eswatini, Ethiopia, Gabon, Gambia, Ghana, Guinea-Bissau, Kenya, Lesotho, Liberia, Madagascar, Malawi, Mali, Mauritania, Mauritius, Mozambique, Namibia, Niger, Nigeria, Rwanda, Sao Tome and Principe, Senegal, Seychelles, Sierra Leone, South Africa, Sudan, Tanzania, Togo, Uganda, Zambia and Zimbabwe

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