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Declining population and GDP growth

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Businesspeople and politicians seem to be afraid that population reduction will be accompanied by economic recession. In this paper we examine the experience of some countries of various sizes in which population has been declining and observe how GDP, GDP per capita, unemployment rate, and labour force participation rate are evolving during the period that population is declining. Using the pooled mean group (PMG) estimation method, we find that population decline can go hand in hand with growing GDP and increasing per capita GDP, and at the same time the labour participation rate may increase and unemployment may fall.

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Introduction

Population is an important variable in the economy and its changing size has always been a source of concern among economists and other scientists. As far back as the fourth century B.C., Plato (*Laws*) and Aristotle (*Politics*) were concerned about overpopulation and suggested a constant land-population ratio (Plato 1926; Aristotle 1932). In the early 16th century, Thomas More wrote his *Utopia*, where every city has a constant number of six thousand families (More 1551). At the end of the 18th century, Malthus published anonymously his *Essay on the Principle of Population* and five years later, in 1803, an enlarged version appeared with his name on it, where he suggests ways for population reduction in order to avoid poverty (Malthus 1803).

More recently, Alvin Hansen, in his presidential address to the American Economic Association in 1938, expresses fears that the decline of population growth will lead to a reduction of investment. If population declines, an important outlet for investment will be closed. Thus, the idea of secular stagnation was introduced (Hansen 1939). A year earlier Keynes (1937) was arguing for population stability when he was saying that, with no major wars and no important increases in population, the economic problem might be solved within a hundred years. The first reaction to Hansen's fears came from Schumpeter (1942, chapter X) who argued that population ageing and population decline do not need to restrict output neither from the demand side nor from the supply side[1].

In the years following the end of the Second World War, when the world population was rapidly growing, the interesting question was not how the low rates of population growth might affect total output but exactly the opposite, i.e. how the very high growth rates might affect output. During the 1920–1930 and the 1930–1940 decades the world population grew by 9.2 and 10.6%, respectively, whereas in the next two decades the growth rates were 9.1 and 20.8% (Gapminder 2022). Simon Kuznets, in a 1967 paper, examined the question "to what extent does a high rate of population growth impede the growth of product per capita" (Kuznets 1967). A year later the publication of Paul Ehrlich's "The Population Bomb" made the population explosion a world issue (Ehrlich 1968).

In recent decades, the world population continues to increase but at lower rates (1.35% in 2000 and 1.01% in 2020). The same is true for most countries but at lower rates. For the period 2000–2020, the annual population growth rates declined from 1.13 to 0.96% in the USA, from 0.69 to 0.27% in France, from 0.05 to −0.49% in Italy, from 0.79 to 0.24% in China, from 1.82% to 0.96 in India, etc. (World Bank 2023). Declining rates of growth lead to an aging population, although the total population may be growing. The fast-growing world population has motivated a large number of studies on the effects of population growth on the economy and the environment and the optimal population size[2]. A different line of research is motivated by the aging of population due to the reduced, but still positive, rates of population growth. These studies examine the effects of population aging on GDP per capita and on other macroeconomics variables.[3] At present, there are some countries which experience not just reduced rates of population growth but declining or stable population. After 1990 and the dissolution of the USSR some countries which were members of the USSR experienced a significant reduction of their populations. The same is true for some countries which were under the domination of the USSR. In recent years Japan, Italy, and Portugal are also experiencing population decline.[4]

The effect of declining population on growth and per capita income is also examined in the context of modern growth theory. Elgin and Tumen (2012) have constructed a model of fertility and growth in advanced economies and come to the conclusion that negative population growth and positive change in per capita consumption can coexist. Jones (2022) examines fully endogenous and semi-endogenous growth with declining population and concludes in both cases that GDP per person will increase asymptotically to a certain level while population declines. He calls this "the Empty Planet result". Strulik (2022) also arrives at the result that declining population does not need to lead to a pessimistic outlook as his model predicts continuing economic growth with declining population. Similar results are obtained by Sasaki and Hoshida (2017) who find that with a declining population the long-run rate of technological change becomes zero, total output declines, but per capita output increases. The main factor for these results is human capital in some form.

In these models and in the relevant literature (see e.g. Tamura 2006; Tamura and Simon 2017) population change is the result of family decisions whereas in the countries we examine, with the exception of Japan, Portugal, and Italy, population decline is the result of major political changes that have resulted in very significant migration flows.

In this paper we examine data from nineteen countries with declining population in recent years and increasing GDP and, therefore, increasing per capita GDP. Of course, we are not implying that population decline directly causes GDP growth, but only that population decline may bring about changes in other variables that positively affect GDP and *a fortiori* raise per capita GDP.

Possible effects of population decline

Population decline is expected to have effects on the supply side of the economy as well as on the demand side. Generally speaking, on the supply side, a decline in population implies a reduction of labour supply (because population is the source of labour) and a fall of the labour input in production; and on the demand side, a reduction in the demand of consumption goods and services and of housing because these goods are demanded by people, and by extension a reduction in the demand for investment. The effect of these changes is expected to be, sooner or later, a fall in gross domestic product. Also, a reduction of population means an increase in the dependency ratio which involves risks for the viability of the pension systems. These are reasons that cause concern about the future of economies with declining population.

On the other side, it is argued that population growth inevitably means growth of production and therefore increasing environmental problems in numbers and in intensity. The detrimental effects of economic growth on the environment are well documented (Meadows et al. 1974, 2004; Schade and Pimentel 2010; Díaz et al. 2019; Bradshaw and Brook 2014; Bradshaw et al. 2021; O'Neil et al. 2010; Daily et al. 1994). Climate change, loss of biodiversity, deforestation, pollution, degradation of land for production are some of the often mentioned effects of human activity on the environment, which undermines future growth and well-being (Wackernagel et al. 2019; Crist et al. 2022; Ripple et al. 2022; Lianos and Pseiridis 2021).

In this paper we examine how some economic variables have changed in nineteen countries with declining population. The decline of population may cause an increase in the labour participation rate particularly if population reduction is accompanied by higher wages and more opportunities for employment. Also, unemployed people may find jobs easily and therefore the unemployment rate may fall. It is also reasonable to expect that as labour becomes scarcer and wages increase, labour saving technologies may be introduced in the production process leading to higher per capita product, more efficient use of labour, and reorganization of business.

It was said earlier that on the demand side, population decline may lead to lower consumption and lower investment in capital that is needed for the production of consumption goods. But it may also lead to a change in the pattern of consumption. The part of income that was intended for the care of the second or third child may be spent for better care of the first two (better education, healthcare, etc.). Also, the propensity to consume may increase as low income families earn higher incomes (because of higher wages and higher participation in the labour market) and therefore feel less uncertain about their economic situation.

Other changes of economic significance may also take place as a result of less population. For example, the fall in population density, particularly in big cities, may reduce commuting time and increase leisure time and the demand for goods used at leisure time. Also, a smaller population in high population density cities may reduce crime rates and the costs associated with citizens' protection and thus money may become available for other uses. Agricultural land per capita will increase, farm fragmentation may be reduced and thus productivity in the agricultural sector may increase. Smaller families will mean increased bequeaths per individual and therefore more wealth per family and higher propensity to consume, etc.[5]

To the factors mentioned above some additional ones can be mentioned which are relevant for the countries we examine. The dataset we use in this paper covers short periods in the recent economic history of nineteen countries sixteen of which (with the exemption of Japan, Italy and Portugal) were members of the Soviet Union or of the Soviet block or their political regime was not democratic. Therefore, the fall of the Soviet Union in 1992 brought drastic changes to their political system and to the economy. Six of them are relevant to our examination of the effects of population reduction. First, all of these countries experienced flows of emigration mainly to European countries. Second, emigration also meant loss of young and educated labour force. Third, migrant remittances increased disposable incomes and consumption of their families in the country of origin. Fourth, the reorganization of firms according to the free market system may have introduced technological innovations in the production methods. Fifth, significant capital flows may have been invested in these countries. Sixth, the political liberties that allow freedom of choice may raise productivity because young people can choose professions in which they have an inclination or a talent and thus become more productive. The last three factors, i.e. reorganization of firms, foreign investment, and political liberties, are expected to have resulted in significant increases in labour productivity. These three factors have introduced embodied and disembodied technological changes as a result of a major institutional change.

It should be noted that the effects of population decline may be different in the short run and in the long run. For example, the structure of demand may change immediately as the age structure of population changes. Consumer taste changes and new technologies may take longer.

Data

In this paper we examine the relationship between the declining population and GDP, GDP per capita, labour force participation rate, and unemployment rate in nineteen countries. Some of these countries were members of the USSR, some were members of the Soviet Block, some were part of Yugoslavia, and some were independent. For most of these countries the decline of population is mainly the result of substantial out-migration flows after the fall of the communist regimes in 1991 and the breaking up of Yugoslavia.

The population decline rates differ substantially between countries, as shown in Table 1. The rate of population decline ranged from 28 and 25% in Latvia and Bosnia-Herzegovina, to 6 and 2.5% in Hungary and Russia. For Portugal, Italy, and Japan population increased between 2.5 and 5.5% during 1990–2019. However, population in these three countries declined during more recent years: in Japan it declined by 1% in 9 years (2011–2019), in Italy by 1.5% in 5 years (2015–2019), and in Portugal by 2.5% in 8 years (2011–2018). The rates of change of our variables of interest for the years 2000-2020 are provided in Table 2.

The data sources used in our study are shown in Table 3.

Table 1 Rates of population decline for 19 countries, 1990–2019.

Country	Population in 1990	Population in 2019	Population change 1990–2019	Annual compound rate of change 1990–2019
Albania	3,286,542	2,854,191	−13.2%	−0.47%
Armenia	3,556,539	2,820,602	−20.7%	−0.77%
Belarus	10,193,831	9,419,758	−7.6%	−0.26%
Bosnia-Herzegovina	4,494,310	3,360,711	−25.2%	−0.96%
Bulgaria	8,718,289	6,975,761	−20.0%	−0.74%
Croatia	4,777,368	4,065,253	−14.9%	−0.54%
Estonia	1,569,174	1,326,898	−15.4%	−0.56%
Georgia	4,802,000	3,720,161	−22.5%	−0.85%
Hungary	10,373,988	9,771,141	−5.8%	−0.20%
Italy	56,719,240	59,729,081	5.3%	0.17%
Japan	123,478,000	126,633,000	2.6%	0.08%
Latvia	2,663,151	1,913,822	−28.1%	−1.10%
Lithuania	3,697,838	2,794,137	−24.4%	−0.93%
Moldova	2,965,978	2,664,224	−10.2%	−0.36%
Portugal	9,983,218	10,286,263	3.0%	0.10%
Romania	23,201,835	19,371,648	−16.5%	−0.60%
Russia	147,969,407	144,406,261	−2.4%	−0.08%
Serbia	7,586,000	6,945,235	−8.4%	−0.29%
Ukraine	51,891,400	44,386,203	−14.5%	−0.52%

Sources of Data: World Bank Indicators, see Table 3.

Estimating methodology

A cointegration analysis has been used to examine the long-run relationship between (i) the per capita GDP and population, (ii) per capita GDP and labour participation rate, and (iii) total GDP and unemployment rate with panel data. By checking for the existence of a cointegrated combination of two or more series, cointegration analysis is used to determine whether there is a statistically significant relationship between two or more variables. Two or more time series can be referred to as cointegrated, and have an equilibrium relationship if their combination has a low order of integration. In this case, cointegration analysis must be utilised instead of conventional linear regression methods because the latter will yield false (spurious) results when used in non-stationary time series.

We estimate three empirical models that examine the three long-term relationships. The general models used are:

$$GDP_{it} = f\left(POP_{i,t}\right) \tag{1}$$

$$GDP_{it} = f\left(LABOR_{i,t}\right) \tag{2}$$

$$TOT\_GDP_{it} = f\left(U\_ILO_{i,t}\right) \tag{3}$$

where i denotes country i; t denotes time (annual data is used); $GDP_{i,t}$ is per capita GDP of country i at time t in PPP (in constant 2017 USD); $POP_{i,t}$ is the population of country i at time t; $LABOR_{i,t}$ is the labour participation rate (ILO data) in country i at

Table 2 Rates of change in GDP (total and per capita), population, labour force participation, and unemployment for 19 countries 2000–2020.

Country	GDP	GDP per capita	Population	Labour force participation	Unemployment
Albania	107%	125%	−8.1%	−6%	−31%
Armenia	202%	241%	−11%	−0.4%	10%
Belarus	124%	139%	−6.0%	7.3%	−67%
Bosnia-Herzegovina	67%	110%	−21%	10%	−42%
Bulgaria	82%	114%	−15%	11%	−68%
Croatia	33%	47%	−9.4%	−2.3%	−53%
Estonia	92%	102%	−4.8%	7.0%	−48%
Georgia	159%	184%	−8.7%	−1.1%	8.4%
Hungary	54%	61%	−4.5%	15%	−35%
Italy	−5.3%	−9.3%	4.4%	0.8%	−15%
Japan	9.4%	10%	−0.5%	−0.7%	−41%
Latvia	89%	135%	−20%	10%	−43%
Lithuania	114%	168%	−20%	3.9%	−47%
Moldova	117%	141%	−10%	−30%	−55%
Portugal	5.4%	5.4%	0.1%	−4.6%	78%
Romania	105%	139%	−14%	−15%	−28%
Russia	79%	82%	−1.7%	0.6%	−47%
Serbia	88%	105%	−8.2%	−2.6%	−28%
Ukraine	49%	66%	−10%	−3.7%	−19%

Sources of Data: World Bank Indicators, see Table 3.

Table 3 Data sources.

Indicator Name	Sources	Indicator code
Unemployment, total (% of total labour force) (national estimate).	ILO via World Bank	SL.UEM.TOTL.ZS
Population, total.	World Bank	SP.POP.TOTL
GDP per capita, PPP (constant 2017 international $).	World Bank	NY.GDP.PCAP.PP.KD
GDP (constant 2015 US$).	World Bank	NY.GDP.MKTP.KD
External balance on goods and services (constant LCU).	World Bank	NE.RSB.GNFS.KN
Labour force participation rate, total (% of total population ages 15+) (modeled ILO estimate).	ILO via World Bank	SL.TLF.CACT.ZS
Historical population data.	Gapminder, v. 7	
Gross Average Monthly Wages by Country and Year.	United Nations Economic Commission for Europe	n/a
Average annual wages.	OECD.Stat	n/a
Median hourly earnings, all employees (excluding apprentices) by sex.	Eurostat	EARN_SES_PUB2S
Average monthly real wage for Armenia.	CEID Data	n/a
Consumer Price Index.	World Bank	FP.CPI.TOTL

time t; $TOT\_GDP_{i,t}$ is the total GDP of country i at time t in constant 2015 USD; and $U\_ILO_{i,t}$ is the unemployment rate (ILO data) in country i at time t.

Finding the long-term relationship is particularly important if the econometric model is used for policy planning in the long-run. The long-term effects of regressands and the independent variables of the three models are examined using datasets from 19 countries. The method used is the pooled mean group (PMG) method which can be characterised as a panel error correction model (ECM), where the long-run effects are estimated from an autoregressive distributed lags (ARDL) model (Pesaran and Shin 1999).

The typical methods to estimating panel data models fall into two categories: mean-group methods, which involve estimating separate regressions for each country and averaging the country-specific coefficients, and dynamic fixed effects models (with control for country-specific effects) which impose homogeneity on all slope coefficients while only allowing the intercepts to vary across countries (see, for example, Arellano and Bond 1991; Arellano and Bover 1995). Pesaran and Smith (1995) criticise the former class of models, claiming that when there is slope heterogeneity, heterogeneity bias affects the estimates of convergence. Because outlier countries may have a significant impact on the averages of the country coefficients in the latter type of models, the estimator may be ineffective. The PMG method offers a middle ground between dynamic fixed effects methods, which impose homogeneity on all slope coefficients, and the mean group method, which does not impose any kind of homogeneity on slope coefficients. The PMG method imposes homogeneity on the long-run coefficients but permits variation among countries in the short-run coefficients, adjustment speed, and error correction variances. Consequently, it is more effective in comparison to the mean group method and less constrained than the dynamic fixed effects method (Pesaran and Shin 1999). The PMG method's long-run homogeneity hypothesis enables the direct identification of the parameters of variables that have an impact on the dependent variable's "steady-state" trajectory.

Consequently, we decided to utilise the PMG method as an error correction method in the panel data models since it offers two benefits over the dynamic fixed effects alternatives: averaging might conceal the dynamic relationship between the regressand and the regressor(s), particularly when countries have different macroeconomic characteristics, and especially when the population effect and labour participation effects on the per capita GDP and unemployment effects on total GDP might be different across countries. This is because (a) averaging results in a loss of information that can be used to more accurately estimate the coefficients of interest while (b) allowing for parameter heterogeneity across countries.

Additionally, asymmetric changes in population were introduced by the POP^{+} and POP^{-} variables, the hypothesis being that large changes in these two variables do not affect with the same intensity the per capita GDP as low changes. These variables for the introduction of asymmetries in the POP variable were constructed following Shin et al. (2014) and (Greenwood-Nimmo et al. 2012, 2013) with the difference that for the decomposition of the variable into POP^{+} and POP^{-} the mean threshold has been used instead of the zero threshold[6]. This was to avoid having a low number of effective observations in one regime (Greenwood-Nimmo et al. 2012, 2013). Consequently, $POP_{i,t}^{+}=\sum_{j=1}^{t}\max(\Delta POP_{i,j},\overline{POP_{i}})$, $POP_{i,t}^{-}=\sum_{j=1}^{t} min(\Delta POP_{i,j},\overline{POP_{i}})$, where the bar indicates the average of the variable, and t and i denote time (measured in years) and country, respectively. Note that the mean of the variable is different for each cross-section (country).

The PMG method also has the benefit of generating consistent estimates of the parameters in the long-run relationship between integrated and stationary variables. This allows the model to be estimated when both I(0) and I(1)[7] variables are present, whereas other methods only allow I(0) or I(1) variables.

However, the PMG method demands that the variables not be I(2) since this would lead to false findings. In order to confirm that the co-integrating variables are I(0) or I(1) and not I(2), we analyse the order of integration of the variables examined before moving further with the estimation of the model. The Im, Pesaran, and Shin panel unit root test has been used for this.

The values of the panel unit root test are presented in Table 4 for the variables used in all three estimated models. The null hypothesis (H_0) of a unit root (non-stationarity) in some panels (countries in this case) is tested against the alternative. H_0 was rejected at the 1% level of statistical significance for $U\_ILO_{i,t}$ (unemployment rate) at the 5% level of statistical significance. The remaining variables used as determinants in the three models and the regressand were found to be non-stationary at their level for all panels while they were found to be stationary at their first difference. Therefore, it is concluded that the variable $U\_ILO_{i,t}$ is I(0) while $GDP_{i,t}$ (per capita GDP), $GDP\_TOT_{i,t}$ (total GDP), $LABOR_{i,t}$ (labour participation rate), and both the asymmetries variables $POP_{i,t}^{+}$, $POP_{i,t}^{-}$ are I(1).

Since all three equations contain I(0) and I(1) variables but not I(2), the PMG modelling can be applied. The responsiveness of cointegrated variables to any deviation from long-run equilibrium is one of their key characteristics. In order to estimate the rate of adjustment to the long-run relationship while allowing for unconstrained cross-section heterogeneity in the adjustment dynamics and fixed effects, the PMG method is used to an ECM.

Table 4 Im, Pesaran, and Shin panel unit root test results[8].

Series	Level		First difference	
	Statistic	Probability	Statistic	Probability
$GDP_{i,t}$	5.49	1.00	−10.18**	<0.01
$GDP\_TOT_{i,t}$	3.27	0.99	−10.64**	<0.01
$POP_{i,t}^{+}$	−1.56	0.06	−6.52**	<0.01
$POP_{i,t}^{-}$	1.25	0.89	−7.35**	<0.01
$LABOR_{i,t}$	−0.80	0.21	−6.02**	<0.01
$U\_ILO_{i,t}$	−5.83**	<0.01		

Source: Authors' estimates.
The null hypothesis of a unit root is tested against the alternative. Two asterisks denote significance at least at the 1% level.

Following Pesaran and Shin (1999), the PMG restricted version of (1), (2), and (3) is estimated on pooled cross-country time-series data as:

$$\Delta Y_{i,t}=\varphi_{i}\left(Y_{i,t-1}-\sum_{k=1}^{\mu}\vartheta_{k,i}G_{k,i,t}\right)+\sum_{j=1}^{p-1}\lambda_{ij}\Delta Y_{i,\,t-j} + \sum_{k=1}^{\mu}\sum_{j=0}^{q-1}\beta_{k,i,j}\Delta G_{k,i,t-j}+\nu_{i}+\varepsilon_{i,t} \tag{4}$$

where $i=1,\ldots,19$ and denotes countries; $t=1,\ldots,32$ and denotes time; Δ is the first-difference operator; $Y_{i,t}$ is the regressand of each of the three models in (1) to (3); $\mu=2$ for (1) while $\mu=1$ for (2) and (3) and is the number of determinants; $G=(POP_{i,t}^{+}, POP_{i,t}^{-})$ for (1), $G=(LABOR_{i,t})$ for (2) and $G=(U\_ILO_{i,t})$ for (3) is the vector with the explanatory variables[9]. The parameter φ_i is the error-correcting speed of adjustment to the long-run relationship. This parameter is of particular importance because it shows the existence (or not) of cointegration among the variables. Cointegration exist if φ_i is found to be negative and statistically significant. Furthermore, the estimated coefficients of the determinants $\vartheta_{k,i}$s show the long-run relationship between the variables while the $\beta_{k,i}$s are their short-run coefficients. ν_i is the country-specific fixed-effect, ε is a time-varying disturbance term, and p and q are the number of lags.

The following stages provide a basic explanation of the PMG method. First, the model described by (4) must have its ARDL order identified. The value of p for the dependent variable and q for each regressor must therefore be determined. The lag order of the ARDL was established using the Akaike Information Criterion (AIC)[10] lag selection criterion, and Eq. (4) was estimated for each cross-section (country) separately for (1), (2) and (3). For the determination of the lag order of the ARDL model for each country, a maximum number of four lags in Eq. (4) was considered. Then, using the most common lag order for each variable across all cross-sections, the final form of (4) for the estimation of (1), (2), and (3) was as follows:

$$\begin{aligned}\Delta GDP_{i,t}&=\varphi_{i}\left(GDP_{i,t-1}-\vartheta_{1,i}POP_{i,t}^{+}-\vartheta_{2,i}POP_{i,t}^{-}\right)\\&\quad+\lambda_{1}\Delta GDP_{i,t-1}+\lambda_{2}\Delta GDP_{i,t-2}+\lambda_{3}\Delta GDP_{i,t-3}\\&\quad+\lambda_{4}\Delta GDP_{i,t-4}+\beta_{1,i,0}POP_{i,t}^{+}+\beta_{1,i,1}POP_{i,t-1}^{+}\\&\quad+\beta_{1,i,2}POP_{i,t-2}^{+}+\beta_{1,i,3}POP_{i,t-3}^{+}\beta_{1,i,4}POP_{i,t-4}^{+}\\&\quad+\beta_{1,i,5}POP_{i,t-5}^{+}\beta_{2,i,0}POP_{i,t}^{-}+\beta_{2,i,1}POP_{i,t-1}^{-}\\&\quad+\beta_{2,i,2}POP_{i,t-2}^{-}+\beta_{2,i,3}POP_{i,t-3}^{-}+\beta_{2,i,4}POP_{i,t-4}^{-}\\&\quad+\beta_{2,i,5}POP_{i,t-5}^{-}+\nu_{i}+\varepsilon_{i,t}\end{aligned}\tag{5}$$

$$\begin{aligned}\Delta GDP_{i,t}&=\varphi_{i}\left(GDP_{i,t-1}-\vartheta_{1,i}LABOR_{i,t}\right)+\lambda_{1}\Delta GDP_{i,t-1}\\&\quad+\beta_{1,i,0}\Delta LABOR_{i,t}+\beta_{1,i,1}\Delta LABOR_{i,t-1}\\&\quad+\beta_{1,i,2}\Delta LABOR_{i,t-2}+\beta_{1,i,3}\Delta LABOR_{i,t-3}\\&\quad+\beta_{1,i,4}\Delta LABOR_{i,t-4}+\nu_{i}+\varepsilon_{i,t}\end{aligned}\tag{6}$$

$$\begin{aligned}\Delta TOT\_GDP_{i,t}&=\varphi_{i}\left(TOT\_GDP_{i,t-1}-\vartheta_{1,i}U\_ILO_{i,t}\right)\\&\quad+\lambda_{1}\Delta TOT\_GDP_{i,t-1}+\lambda_{2}\Delta TOT\_GDP_{i,t-2}\\&\quad+\lambda_{3}\Delta TOT\_GDP_{i,t-3}+\beta_{1,i,0}\Delta U\_ILO_{i,t}\\&\quad+\beta_{1,i,1}\Delta U\_ILO_{i,t-1}+\beta_{1,i,2}\Delta U\_ILO_{i,t-2}\\&\quad+\beta_{1,i,3}\Delta U\_ILO_{i,t-3}+\beta_{1,i,4}\Delta U\_ILO_{i,t-4}+\nu_{i}+\varepsilon_{i,t}\end{aligned}\tag{7}$$

Second, using a maximum likelihood estimator, the long-run coefficients $\vartheta_{k,i}$s, are jointly estimated across countries. Last but not least, using the maximum likelihood method and the estimates of the long-run coefficients that were obtained in the previous step, the short-run coefficients, λ_{ij}s and $\beta_{k,i,j}$s, the speed of adjustment φ_i, the country-specific intercepts ν_i, and the country-specific error variances are estimated on a country-by-country basis.

The following specification requirements need to be verified against the PMG estimates: The model is first evaluated for dynamic stability (existence of a long-run relationship). The coefficient of the error correction term must be negative and not less than −2 for our model to be dynamically stable (i.e., within the unit circle)[11]. For (5), φ_i has a value of −0.293, and is less than 1% statistically significant. The same applies for (6) and (7) where the φ_i has a value of −0.076 and −0.125, respectively. As a result, the prerequisite for dynamic stability has been met. Testing for co-integration between the dependent and explanatory variables is a further requirement.

A co-integration, indicated by a negative and statistically significant coefficient on the error correction term φ_i, is necessary. This coefficient's value displays the percentage change in any disequilibrium between the explanatory and dependent variables that is resolved within a given time frame (one year, in our case). Its value denotes how quickly the long-run equilibrium is being adjusted. In our situation, for (5) the value of φ_i is −0.293, indicating the existence of a long-term link between the variables and the correction of 29.3% of any short-term disequilibrium between the dependent and explanatory variables in one time period. A slower adjustment to long-run equilibrium is found for (6) and (7) since a correction of 7.6 and 12.5%, respectively, of any short-term disequilibrium between the dependent and explanatory variable is made in one time period.

Thirdly, the PMG estimator requires that the long-run coefficients be equal across all cross-sections, as was previously mentioned. When the applied limitations are valid, that is, when the long-run coefficients are the same across countries, this pooling across cross-sections produces accurate and reliable estimates. The PMG results are inconsistent if the true model is heterogenous in the slope parameters across cross-sections. Using a Hausman-type test, this homogeneity hypothesis is examined. The comparison of the PMG and mean group (MG) estimators forms the basis of this test. The level of statistical significance (p) for the Hausman test statistic was 0.508 and its value was $\chi^2_2 = 1.35$ for (5), while $p = 0.282$ and $\chi^2_1 = 1.16$ for (6) and $p = 0.240$ and $\chi^2_1 = 0.62$ for (7). Therefore, it is concluded that all three models are homogenous in the slope parameters across countries, and the null hypothesis that the variation in coefficients is not systematic cannot be rejected.

Table 5 Long-run and short-run effects, with asymmetric responses, of the population on per capita GDP.

Variables	Coefficient	Standard error	*p*-value
Long-run coefficients			
$POP^{+}_{i,t}$	0.0177**	0.0054	0.001
$POP^{-}_{i,t}$	0.0085*	0.0039	0.028
Short-run coefficients			
ΔGDP_{t-1}	−0.2475	0.1888	0.190
ΔGDP_{t-2}	1.3506**	0.0494	< 0.001
ΔGDP_{t-3}	−0.8493**	0.0544	< 0.001
ΔGDP_{t-4}	0.2018**	0.0188	< 0.001
$\Delta POP^{+}_{i,t}$	0.0133**	0.0035	< 0.001
$\Delta POP^{+}_{i,t-1}$	−0.0443*	0.0174	0.011
$\Delta POP^{+}_{i,t-2}$	0.0447	0.0277	0.107
$\Delta POP^{+}_{i,t-3}$	−0.0107	0.0221	0.628
$\Delta POP^{+}_{i,t-4}$	−0.0134	0.0125	0.285
$\Delta POP^{+}_{i,t-5}$	0.0058	0.0036	0.103
$\Delta POP^{-}_{i,t}$	0.000024	0.0023	0.992
$\Delta POP^{-}_{i,t-1}$	−0.1517	0.1694	0.370
$\Delta POP^{-}_{i,t-2}$	0.0390	0.0552	0.479
$\Delta POP^{-}_{i,t-3}$	−0.0617	0.0755	0.414
$\Delta POP^{-}_{i,t-4}$	0.0397	0.0491	0.418
$\Delta POP^{-}_{i,t-5}$	−0.0139	0.0161	0.387
Intercept	−74336.44**	28874.13	0.010
Joint Hausman test	1.35		0.508
Error correction coefficient (φ)	−0.2934**	0.0301	< 0.0001

Dynamic Specification: ARDL (4, 5, 5)
Model selection method: Akaike information criterion (AIC)
Maximum likelihood method, dependent variable lags: 4 (automatic selection), Dynamic regressors (5 lags, automatic selection)

Estimator	Pooled Mean Group (PMG) controlling for country-fixed effects
No. of countries	19
Period	1990–2021 (32 time periods)
No. of observations	608

Source: Authors' estimates.
** and * denote statistical significance at the 1% and 5% level, respectively.

Results

The estimation results are presented in Tables 5–7.

From Table 5 we see that population changes affect very little the change in the per capita GDP in the long-run: the value of the $POP^{+}_{i,t}$ coefficient is 0.018 and of the $POP^{-}_{i,t}$ 0.009. However, there is an asymmetric effect of the population change on the per capita GDP because by using a Wald test of equality of the two coefficients the null hypothesis of equality is rejected at a high level of statistical significance ($\chi^2_1 = 76.57$, $p < 0.001$). The latter means that a reduction in population reduces per capita GDP less than the effect that an increase in population has on the increase of the per capita GDP; both effects though are very small.

From Table 5 we see also the value and the statistical significance of the short-run coefficients of both regimes of population changes for up to five years' time-lag. We see that population changes, either increases or decreases, do not affect the per capita GDP as all short-run coefficients of both regimes are statistically insignificant at the 1% level of statistical significance.

Table 6 and Table 7 present the estimation results of (6) and (7), i.e. the effects of labour participation on per capita GDP and the effects of unemployment on total GDP, respectively. The long-run coefficients are statistically significant at the 1‰ level of statistical significance and are of the expected sign as the coefficient of the labour participation rate is positive (the higher the labour participation rate the higher is the per capita GDP) and the coefficient of the unemployment rate is negative (the higher the unemployment rate the less is the total GDP). Again, their value is small; it is 0.017 for the labour participation rate and −0.019 for the unemployment rate.

The short-run coefficients of previous periods are statistically insignificant except for the current period for both (6) and (7) and their sign and value are the same as that of the long-run period.

Therefore, we conclude that, in countries which experienced a decline in their population size, population changes up to five years back do not affect the changes in per capita GDP; additionally, the long-run effects of increases and decreases of the population on per capita GDP are very small, with the latter affecting considerably less the change in total GDP than the former, as described above. Furthermore, there are no short-run effects found of the labour force participation on per capita GDP and the unemployment rate on total GDP. Long-run effects do exist and show that the labour force participation rate positively affects per capita GDP and that the unemployment rate negatively affects total GDP. However, in both estimations, the coefficient's value is very small.

Table 6 Long-run and short-run effects of labour force participation rate on per capita GDP.

Variables	Coefficient	Standard error	*p*-value
Long-run coefficients			
$LABOR_{i,t}$	0.0168**	0.0063	0.008
Short-run coefficients			
ΔGDP_{t-1}	0.0030	0.0070	0.667
$\Delta LABOR_{i,t}$	0.0173*	0.0076	0.024
$\Delta LABOR_{i,t-1}$	−0.020	0.0113	0.072
$\Delta LABOR_{i,t-2}$	−0.0120	0.0213	0.573
$\Delta LABOR_{i,t-3}$	0.0041	0.0076	0.589
$\Delta LABOR_{i,t-4}$	0.0089	0.0056	0.112
Intercept	0.8744**	0.2685	0.001
Joint Hausman test	1.16		0.282
Error correction coefficient (φ)	−0.0760**	0.0238	0.002
Dynamic Specification: ARDL (1, 4)			
Model selection: Akaike information criterion (AIC)			
Maximum likelihood method, dependent variable lags: 1 (automatic selection), Dynamic regressors (4 lags, automatic selection)			
Estimator	Pooled Mean Group (PMG) controlling for country-fixed effects		
No. of countries	19		
Period	1990–2021 (32 time periods)		
No. of observations	608		

Source: Authors' estimates.
Notes: ** and * denote statistical significance at the 1% and 5% level, respectively.

Table 7 Long-run and short-run effects of unemployment rate on total GDP.

Variables	Coefficient	Standard error	*p*-value
Long-run coefficients			
$U\_ILO_{i,t}$	−0.0187**	0.0041	<0.0001
Short-run coefficients			
ΔTOT_GDP_{t-1}	−0.1765**	0.0602	0.004
ΔTOT_GDP_{t-2}	0.0306	0.0578	0.596
ΔTOT_GDP_{t-3}	0.0550	0.0501	0.273
$\Delta U\_ILO_{i,t}$	−0.0164**	0.0029	<0.0001
$\Delta U\_ILO_{i,t-1}$	−0.0022	0.0021	0.301
$\Delta U\_ILO_{i,t-2}$	0.0015	0.0027	0.574
$\Delta U\_ILO_{i,t-3}$	−0.0009	0.0020	0.639
$\Delta U\_ILO_{i,t-4}$	−0.0016	0.0014	0.250
Intercept	3.3903**	0.9107	0.0002
Joint Hausman test	0.620		0.240
Error correction coefficient (φ)	−0.1248**	0.0041	< 0.0001
Dynamic Specification: ARDL (3, 4)			
Model selection method: Akaike information criterion (AIC)			
Maximum likelihood method, dependent variable lags: 3 (automatic selection), Dynamic regressors (4 lags, automatic selection)			
Estimator	Pooled Mean Group (PMG) controlling for country-fixed effects		
No. of countries	19		
Period	1990–2021 (32 time periods)		
No. of observations	608		

Source: Authors' estimates.
** and * denote statistical significance at the 1% and 5% level, respectively.

Comments and conclusions

There seems to be an impression among the general public, businesspeople, and some professionals that population decline is harmful to the economy. Businesspeople in particular are concerned about profits, as wages may increase and demand may stagnate as a result of population decline.[12]

The results of our regressions provide evidence that population decline may not be a danger for the economy. In a sense, our results may be viewed as an empirical confirmation of the results obtained by the growth models mentioned in the introduction. Population decline can go hand in hand with growing GDP and increasing per capita GDP, and at the same time the labour participation rate may increase and unemployment may fall. At least this much is supported by the data from the nineteen countries we examined. One may assume that the introduction of labour-saving technology is also one major factor that prevented GDP from falling when population declined in the countries we examined. From the results found in our study for the effects of population changes on the per capita GDP we can see that population reduction does not need to be disastrous economically. Hence the fears that economic stagnation will follow population decline may be unfounded.

It should be noted that population *decline* is very different from a declining rate of population *growth* that leads to population *increase* and therefore our findings are not strictly comparable with those of studies examining the effects of declining population *growth* rates. Also, the channels through which population decline and population aging each affect GDP and GDP per capita may be different. For instance, Maestas et al. (2023) who examined the relationship between GDP per capita and population aging, have found that two thirds of the reduction in GDP per capita was due to a reduction in labour productivity whereas it can be seen that, during the period we examine, labour productivity as expressed in real wages was increasing (see Table 8 in the Appendix). Also, a reduction in growth of employment per capita reduces GDP per capita whereas in the countries we examined employment per capita has increased as evidenced by the increasing labour force participation rate.

The total population of the nineteen countries examined here was 9 and 6% of the world population in 1990 and 2019, respectively. Would changes like those presented above take place in case the decline in population were a global phenomenon? In such a case, the flows of migration, the volume of international trade, and the demand for resources might decline, and there is no obvious reason to expect that the long run changes would be different from those described above. This could be an idea for further work.

Data availability

The datasets generated during and/or analysed during the current study are available in the Harvard Dataverse repository, https://doi.org/10.7910/DVN/FILTWF.

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Notes

1. In a footnote on p. 115 Schumpeter makes fun of the economists' attempt to forecast future populations. He refers to Malthus, Keynes, and H. Wright and ends the footnote with "Will economics never come of age?".
2. See the many works by Daly on the steady state economy model (Daly 1968, 1972, 1991, 2008, 2019; (Ehrlich and Holdren 1971; Daily et al. 1994; Pimentel et al. 1994; Cohen 1996, 2017; Pimentel et al. 2010; Schade and Pimentel

2010; Lianos 2013, 2018, 2021; Lianos and Pseiridis 2016; Díaz et al. 2019; Bradshaw et al. 2021; Dasgupta et al. 2021).

3 See Acemoglu and Restrepo 2017; Lindh and Malmberg 1999; Feyrer 2007; Gordon 2017; Götmark et al. 2018; Fair and Dominguez 1991; Maestas et al. 2023; Park et al. 2020.

4 See Clark et al. (2010) for a discussion of Japan's case.

5 Additional consequences of population decline are discussed in Coleman and Rowthorn (2011).

6 For robustness other thresholds (median and zero) have also been used. The lag order of equation (5) was found to be the same and the values of the estimated long-run coefficients and their statistical significance were found to be approximately the same. Furthermore, all the estimated short-run coefficients were also found to be statistically insignificant. Results are available upon request from the authors.

7 I(d) denotes the order of the integration of a time series, i.e. it shows the minimum number of differences required to obtain a covariance stationary series.

8 The null hypothesis is the existence of a unit root. For stationarity, the null hypothesis has to be rejected at at least 5% level of statistical significance.

9 The full description of the data used is provided in section 3 (Data), above.

10 The AIC is a measure of the relative quality of a statistical model for a given set of data and, therefore, it provides a means for model selection.

11 See Agiomirgianakis et al. (2017) and Tsounis et al. (2022) for further analysis.

12 Real GDP has increased in all countries except Italy during the two last decades (see Table 2). Real wages have increased in all countries during the 2000-2019 period with the exception of Italy, Japan, and Portugal where they are practically constant (see Table 8 in the Appendix).

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TPL: Conceptualization (lead); methodology; writing – original draft (equal); review and editing (equal). AP: Conceptualization (supporting); data curation; writing-original draft (equal); investigation; formal analysis; visualization; writing–review and editing (equal). NT: Formal analysis; methodology; writing-original draft (equal).

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The authors declare no competing interests.

Ethical approval

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