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Journal of Policy Modeling 45 (2023) 121–138

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Long-run macroeconomic consequences of Taiwan's aging labor force: an analysis of policy options☆

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Received 4 August 2022; Received in revised form 22 November 2022; Accepted 29 December 2022
Available online 4 February 2023

Abstract

Taiwan is poised to become a super-aged society. We found there exist long-run relationships involving key macroeconomic variables and population age shares. The findings indicate that Taiwan's aggregate production exhibits increasing returns to scale where the quality of labor input is the single most important source of growth. The out-of-sample forecast plots envisage that Taiwan's aging labor force does not necessarily decelerate real GDP growth for at least a decade or more. In particular, there are viable policy measures to curb labor shortages due to the shift in the age structure of the labor force caused by population aging.

JEL classification: J11; C32

Keywords: Taiwan; Aging; Conditional ARDL; Quality of labor

☆ This work was supported by the Fundamental Research Grant Scheme, FRGS/1/2019/SS08/USM/02/1, by the Ministry of Higher Education, Malaysia.

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https://doi.org/10.1016/j.jpolmod.2023.01.006
0161-8938/

1. Introduction

Much like most industrial countries, Taiwan is aging. In 2018, one in seven of the economic powerhouse's population was 65 years and over, indicating it has become an aged society (Taiwan News, 2018). In fact, the long-term decline in total fertility[1] and continuous improvement in longevity have accelerated the population aging process. Therefore, the proportion of Taiwanese population aged above 65 is expected to increase to one in five[2] by 2025 (Lin, 2010). In itself, the progressive shift in the age structure (with the ratio of the old to the young exceeding one) could have extensive macroeconomic consequences in the long run, including, but not limited to, the size of the working population and real GDP. With the continued trend of the growing share of older workers in the labor force, the Taiwanese government has raised the workers' legal age of retirement to address the shrinking labor force.[3] In addition, the industrialization process in Taiwan has transformed its production processes from low-skilled to high-skilled manufacturing (Chuang, 1999). So, confronted with a shrinking labor force associated with population aging, the Taiwanese government could engage in tax policies (such as tax holidays, accelerated depreciation, and tax credits for investment) to increase capital intensity in order to cope with the higher relative price of labor. To provide a conducive investment environment, local firms including small and medium enterprises should be given automatic access to bank credit at preferential rates.

Retrospectively, high saving and investment rates with a strong emphasis on attaining tertiary education are among the attributes of Taiwan's economic success. Government spending on education makes up a large share of the budget. In 2020, its total education spending was 928.4 billion New Taiwan dollars, an increase of 21% over the last decade.[4] As a result, the percentage of its population above the age of 15 with high school, technical college and university degrees increased to 47.3% in 2020 from 37.05% a decade ago (see Fig. 1). As highlighted by Lee et al. (1994), the enhancement of the quality of labor input[5] or human capital[6] is the key driving force behind Taiwan's economic growth. Equipping the labor force of tomorrow with education and training could potentially bridge the future working-age population gap. Hence, educational policies on boosting human capital could mitigate the adverse macroeconomic effects of population aging.

Concomitantly, the fiscal burden on the government in the form of growing demand for social welfare and pensions is likely to increase in the foreseeable future, ceteris paribus, due to the rapid rise in the share of the elderly population.[7] As a consequence, fiscal sustainability, in

[1] In 2021, Taiwan's total fertility rate was 1.07 births per woman, which was way below the replacement-level fertility of 2.1 children per woman, leading to a decline in population size (https://www.statista.com/statistics/268083/countries-with-the-lowest-fertility-rates/).

[2] It will be regarded as a super-aged society when the proportion of the population above the age of 65 constitutes 20%.

[3] For instance, the legal retirement age for pension eligibility is raised by one year biennially, such as to 61 in 2018, 62 by 2020, 63 in 2022, 64 by 2024, and 65 by 2026 (see https://www.taiwannews.com.tw/en/news/3361692).

[4] Source: Taiwan's total education expenditure 2020, from www.statista.com/statistics/925203/taiwan-total-education-expenditure/

[5] Quality labor input refers to knowledge and skills that matter for economic growth (Bloom et al., 2008).

[6] Lee et al. (1994) measured the quality of labor input by education attainment.

[7] In 2020, the old-age dependency ratio in Taiwan was 22.5% and is expected to escalate in the decades ahead (https://www.statista.com/statistics/1112465/taiwan-child-and-old-age-dependency-ratio/#:~:text=In%202020%2 C%20the%20child%20and,dependency%20ratio%20of%2040.2%20%.

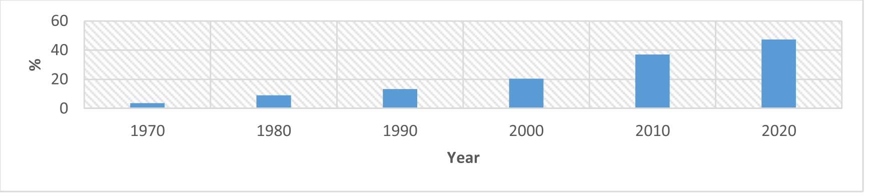

Figure 1. Percentage of the population aged 15 and above with high school, technical college and university degrees, 1970 – 2020. Source: Own calculation.

the long run, becomes questionable, especially since the government's direct tax revenue is anticipated to decline when aging reduces the size of the labor force and in turn active labor income. To meet the increasing government outlays for the expanding elderly population, the government would need to increase borrowing or taxation to finance the accrued social spending. An increase in government borrowing would crowd out domestic investment, which is seen to be detrimental to economic growth. Nevertheless, the extent of the effect of the demographic shift in impeding economic growth is unclear because it is contingent on the macroeconomic dynamics and the competitive forces at play. For example, if the younger cohort has more education than the older cohort (see Lutz et al., 2007), a highly educated labor force would be capable of achieving higher productivity, offsetting their diminished numbers brought on by prior low fertility rates.

The objective of this study is to examine empirically the long run relations among key macroeconomic variables and evolving demographic forces in Taiwan, and to understand their implications for future economic growth and to motivate policy decisions. The empirical model emphasizes the determinants of capital, physical labor, and human capital inputs in an aggregate production function, and how these factors are driven by the impact of demographic changes on saving and investment in the private and public sectors. Among the notable contributions of this study are (i) establishing the existence of long run equilibrium (cointegrating) relations between key macroeconomic variables and demographic factors; (ii) demonstrating the importance of Taiwan's investments in human capital and physical capital to cope with the declining share of working age population; (iii) long run projections of key macroeconomic variables, including real GDP, as driven by age shares of the population presented by the United Nations under their medium assumptions on the future path of fertility; (iv) while it is often said that demography is destiny, the evidence presented in this paper demonstrates that there are viable policy options for Taiwan to mitigate the adverse pressures of population aging.

This paper is organized as follows. Section 2 reviews the major studies in this area with key reference to Taiwan's experience. Section 3 deals with the theoretical underpinnings of the equations relating to demographic change and the key macroeconomic variables. The subsequent section describes the conditional Augmented Autoregressive Distributed Lag (ARDL) framework for cointegration analysis and the data used for this study. The empirical results are reported and discussed in Section 5. Finally, the conclusions and policy implications are provided in Sections 6 and 7.

2. Literature review

As discussed in the previous section, aging demographics can have macroeconomic consequences. However, empirical studies in this area using Taiwan as a case study are relatively few. In one of the earlier studies, Deaton and Paxson (1994) use survey data on expenditures and income from 1976 to 1990 to shed light on the effects of changes in demographic structure on saving, consumption and income growth in Taiwan. Their findings indicate that saving could increase with age, suggesting people do not dis-save when in old age, which contradicts the life-cycle hypothesis that population aging would negatively affect saving. Conversely, using secondary time-series data over the period 1952–1999 for Taiwan, Athukorala and Tsai (2003) confirm a different view from Deaton and Paxson (1994) when the saving function captures the impact of population dynamics, growth of disposable income, inflation, and unemployment, as well as real interest rates. The econometric results show that both the old-age and young-age dependency ratios have a negative impact on the saving rate.

Several other empirical studies examine the impact of aging on economic growth in Taiwan. Hsu (2017) applied the Cobb-Douglas production function to evaluate the impact of population aging on per capita output growth in Taiwan from 1951 to 2014. By decomposing the output equation into the growth of employment, the growth of labor force participation, and the growth of the working-age population, the findings indicate that aging demographics in Taiwan would have an adverse effect on per capita output growth. The empirical results suggest that per capita output growth in Taiwan would start to diminish after the year 2020 if no counteracting forces alter the negative effect of the shrinking working-age labor force associated with population aging. Similarly, a simple regression analysis using quarterly data from 1981 to 2017 by Huang et al. (2019) showed that, an increase in the old-age dependency ratio could have a negative influence on economic growth in Taiwan, implying population aging might decelerate economic development. This finding is consistent with Papapetrou and Tsalaporta (2020). Using a sample of 23 OECD developed countries from 1960 to 2014, the results show that a larger elderly share of population would lead to lower real GDP growth. On the other hand, Hondroyiannis and Papapetrou (2005) find a positive relationship between fertility and real growth for selected European countries. In addition, the possible influence of aging on healthcare expenditures in Taiwan are examined in studies by Shiu and Chiu (2008). Using a cointegration test from 1960 to 2006, the study shows that population aging is one of the key variables[8] that have a positive impact on healthcare expenditures. Hence, it remains an empirical question whether Taiwan's fiscal health, in the long run, is sustainable if the projected aging population is on an upward trajectory. For policy consideration, the available empirical evidence is useful in assisting policy makers to formulate appropriate policies addressing the needs of the aging labor force in the face of rapid population aging in order to achieve inclusive growth and sustainable development.

3. Theoretical framework

In order to examine the long-run macroeconomic implications of demographic changes for Taiwan, the following macroeconomic model is constructed. The aggregate production function for Taiwan's economy is specified as:

$$Y = L^{a_1} H^{a_2} K^{(a_3)} \quad (1)$$

where Y is real output; L is labor input; K is capital stock, H is the human capital. a_1 and a_2 are output elasticity of labor and output elasticity of human capital, respectively, whereas the output

[8] Other key explanatory variables that influence health care expenditures positively are income, life expectancy and the number of practicing physicians (see Shiu & Chiu, 2008).

elasticity of capital is represented by (a_3). Assuming L and H have the same output elasticity ($a_1 = a_2$), and following Wang and Yao (2001), these two inputs are combined into a single skill-adjusted labor input $(LH)_t$. Hence, Eq. (1) can be re-written as:

$$Y = (LH)^{a_1} K^{a_3} \tag{2}$$

Taking logs on both sides of Eq. (2) yields:

$$\log Y = a_1 \log(LH) + (a_3) \log K \tag{3}$$

Eq. (3) shows that the log of real output Y depends on the log of skilled labor LH and the log of real capital K, which are postulated to contribute positively to Y. In turn, skilled labor LH, which can be acquired from higher education and training, is expected to be influenced positively by education attainment as in:

$$LH = b_0 + b_1 VOC + b_2 UNI \tag{4}$$

where *VOC and UNI* are vocational and university attainments, respectively, which can serve as proxies for the level of education.

Eq. (5) for real capital stock K is written as

$$K = c_0 + c_1 WORKING + c_2 RGDP \tag{5}$$

where the ratio of working-age population to total population (*WORKING*) and real GDP (Y) are the main determinants of the real capital stock K.The effect of *WORKING* on K can be either positive or negative, depending on whether the relationship between K and *WORKING* is complementary or substitutable. If K and *WORKING* are complements, firms will have to increase capital inputs to support an expanding labor force in order to produce effectively. On the other hand, a shrinking labor force could lead to a higher labor cost, resulting in substitution from the more expensive labor input to the cheaper capital input if capital and labor are substitutes in production. Hence, the estimated coefficient c_1 can be either positive or negative. Moreover, K can also be explained by the simple accelerator effect, i.e., firms will increase spending on capital goods such as plant and equipment and factories, etc., to meet the increasing aggregate demand when the economy experiences growth. Therefore, the estimated coefficient c_2 is expected to be positive.

In addition, population aging could pose fiscal challenges, especially when the projected share of the old-age population is set to increase over the forecast horizon. Age-related government social expenditures (*SE*)for this study include education, health care, social welfare, and pensions, which can be incorporated in the fiscal balance (*FB*) as follows:

$$FB = TR - TE \tag{6}$$

where *TR* and *TE* are total government revenue and expenditure, respectively. In turn, *TE* can be decomposed into *SE* and other government expenditures (*OGE*)in Eq. (7) as

$$FB = TR - (SE + OGE) \tag{7}$$

Reordering Eq. (7), we have the following:

$$FB = (TR - OGE) - SE \tag{8}$$

$$FB = NFB - SE \tag{9}$$

$$NFB = FB - SE \tag{10}$$

where *NFB* denotes fiscal balance net of (or excluding) *SE*.

Given that SE is positively related to the proportions of young and old populations, the SE equation is expressed as:

$$SE = d_0 + d_1 YOUNG + d_2 OLD \tag{11}$$

where *YOUNG* and *OLD* represent the share of youth and old populations, respectively. d_1 and $d_2$are expected to be positive.

With respect to *NFB* in Eq. (12), the key explanatory macroeconomic variables are real GDP (*Y*) and inflation (*INF*). An increase in *Y* due to an expansion of economic activity is expected to result in an increase in *NFB*, for example, an increase in RGP (real income) increases tax revenues under the progressive income tax system adopted in Taiwan. While *INF* can push taxpayers into higher tax brackets owing to wage indexation, which could increase *NFB* due to the progressiveness of income tax. However, government tends to experience budget overrun when *INF* occurs, especially when it has price effects on government expenditures, e.g. wages. Hence, $e_1$is expected to be positive while $e_2$can either be positive) or negative.

$$NFB = e_0 + e_1 RGDP + e_2 INF \tag{12}$$

The investment demand (*INV*) equation is specified as:

$$INV = f_0 + f_1 WORKING + f_2 RGDP + f_3 IR \tag{13}$$

where *INV* is positively (or negatively) related to *working* when capital and labor are complements (or substitutes) in production. Also, an increase in*INV* occurs when firms see further growth in *real GDP*, which is an impetus for business expansion to satisfy the production upturn. However, an increase in the real interest rate (*IR*) could discourage investment spending because it becomes costlier to finance a business expansion due to higher cost of borrowing. Therefore, f_1 is expected to be either positive or negative, while $f_2$and f_3 are expected to be positive and negative, respectively.

Another key macroeconomic variable that can be influenced by the age structure of the population is the saving rate (*SAV*), which is given by:

$$SAV = g_0 + g_1 YOUNG + g_2 OLD + g_3 RGDP + g_4 IR + g_5 \mathrm{INF} \tag{14}$$

Eq. (14) is based on the life-cycle model (*LCM*) augmented with certain key macroeconomic features of Taiwan. The *LCM* postulates that the working-age cohort has a higher propensity to save because they are the net producers, as opposed to the young and the retired cohorts, who tend to reduce their saving or even dis-save because they are the net consumers. However, retirees may save more for rainy days if the social security systems are inadequate. Therefore, we hypothesize that *YOUNG* has a negative effect on saving ($g_1 < 0$), whereas the impact of the *OLD* on saving is ambiguous. Apart from the demographic variables as determinants of *SAV*, there is also a direct relationship between income (*RGDP*) and saving (*SAV*), according to a standard saving function. As such, g_3 is expected to be positive. The decision on the level of *SAV* can also be influenced by *IR*, with an effect that could either be positive or negative, depending on whether the substitution or income effect dominates. For instance, an increase in *IR* could make saving relatively more attractive than spending due to higher price of present consumption relative to future consumption (substitution effect). At the same time, savers may spend more in response to higher *IR* because of higher interest income from savings (income effect). Therefore, the expected sign for g_4 is ambiguous. In any case, *SAV*could lose its purchasing power when inflation occurs. So *SAV* is negatively related to inflation ($g_5 < 0$).

All in all, the theoretical equations for Taiwan's macroeconomic model are as follows:

Production Function: $Y = (LH)^{a_1} K^{a_3}$

Human Capital Employment: $LH = b_0 + b_1 VOC + b_2 UNI$

Capital Stock: $K = c_0 + c_1 WORKING + c_2 RGDP$

Social Expenditure: $SE = d_0 + d_1 YOUNG + d_2 OLD$

Net Fiscal Balance: $NFB = e_0 + e_1 RGDP + e_2 INF$

Investment Demand: $INV = f_0 + f_1 WORKING + f_2 RGDP + f_3 IR$

Gross Domestic Saving: $SAV = g_0 + g_1 YOUNG + g_2 OLD + g_3 RGDP + g_4 IR + g_5 \mathrm{INF}$

4. Methodology

The theoretical relations presented in the previous section are expanded as fully dynamic ARDL equations for empirical analysis. The ARDL methodology provides a framework for testing the existence of cointegrating equations, relating each macroeconomic variable to demographic forces. Since the age structure of a population evolves slowly and macroeconomic responses to demographic change are also protracted, testing for cointegration is the essential first step in the empirical analysis.

Following Pesaran et al. (2001) and Stefano et al. (2022), we construct conditional ARDL equations as dynamic formulations of the theoretical relations described above. For example, the conditional ARDL equation for a three-variable model is

$$\Delta Y_t = \hat{c} + \hat{\phi} Y_{t-1} + \hat{\gamma} X_{t-1} + \hat{\varphi} Z_{t-1} + \sum_{i=1}^{p-1} \hat{\lambda}_i' \Delta Y_{t-i} + \sum_{j=1}^{q-1} \hat{\delta}_j' \Delta X_{t-j} + \sum_{k=1}^{r-1} \hat{\pi}_k' \Delta Z_{t-k} + \eta \Delta X_t + \omega \Delta Z_t + \varepsilon_t \tag{15}$$

where Y_t is the dependent variable, X_t and Z_t are independent variables. ϕ is the coefficient on the lagged level of the dependent variable, γ and φ are coefficients on the lagged levels of the independent variables. These three parameters determine the existence and nature of the long-run relations and provide the basis for the ARDL cointegration tests. The remaining terms involving the first differences of the three variables incorporate the short-run dynamics. The disturbance term, ε_t, is assumed to be IID (independent and identically distributed) with a zero mean and a finite variance σ^2.

Eq. (1) is equivalent to a conditional error-correction model because it includes the instantaneous differences of X and Z, the explanatory variables, as in Pesaran et al. (2001). To check for cointegration, Pesaran et al. (2001) introduce an F-test for the overall significance of the coefficients on all lagged level variables, and separately a t-test on the coefficient on the lagged dependent variable. To guard against a degenerate case, McNown et al. (2018) propose an

Table 1
Definitions of variables.

Variables	Definition	Source
Real Gross Domestic Product (***RGDP***)	Real Gross Domestic Product (constant 2017 in mil. US$)	PWT, version 10.
Capital stock(***K***)	Real Capital stock (constant 2017 in mil. US$)	PWT, version 10.
Employment (***L***)	Number of persons engaged (in millions)	PWT, version 10
HumanCapital Index (***H***)	Based on years of schooling and returns to education	PWT, version 10.
Total young to total population (***YOUNG***)	Ratio of population aged 0–14 per total population	NDCT
Total working to total population (***WORKING***)	Ratio of population aged 15–64 per total population	NDCT
Total old to total population (***OLD***)	Ratio of population aged 65 and above per total Population	NDCT
Saving (***SAV***)	The percentage of Gross Domestic Saving relative to GDP	NST
Investment (***INV***)	The percentage of Gross Domestic Investment relative to GDP	NST
Fiscal Balance (***FB***)	The percentage of Fiscal Balance relative to GDP	NST
Inflation (***INF***)	Consumer Price Index (CPI) seasonally adjusted	NST
Government Social Expenditure (***SE***)	The percentage of government expenses on education, social benefits and pension funds & health care to GDP	CEIC

Note: PWT is PennWorld Tables, NDCT is National Development Centre Taiwan, NS is National Statistics Taiwan.

additional F-test on the lagged levels of the independent variables. The three tests, therefore, are.i. F_1: Overall F-test on all lagged level terms, H_0: $\phi = \gamma = \varphi = 0$ vs H_1: any $\phi, \gamma, \varphi \neq 0$ii. t: t-test on the lagged level of the dependent variable, H_0: $\phi = 0$ vs H_1: $\phi \neq 0$.iii. F_2: F-test on lagged levels of all independent variables, H_0: $\gamma = \varphi = 0$ vs H_1: any $\gamma, \varphi \neq 0$. Cointegration is confirmed only if all three test statistics are significant.

McNown et al. (2018) develop a bootstrap version of the bounds tests to rule out any inconclusive inference, and this procedure is applied in the cointegration tests of this study. The bootstrap approach also has the advantage that the bootstrap critical values are specific to the statistical properties of the data and the specification of the test equations. Following the recommendations of Li and Maddala (1997), this study applies the residual bootstrap procedure so that the possible non-stationarity of the individual series is preserved. The bootstrap design employed here also follows Li and Maddala (1997) to impose the null hypothesis when generating the dependent variable from the ARDL equation. Furthermore, the residuals are rescaled and recentered in the bootstrap sampling as recommended by Davidson and McKinnon (2005).

Annual data for the period 1960–2019 are used in the estimation. The data have been collected from various sources. Data sources and details of variable construction are given in Table 1. All variables are expressed in natural logarithms in the estimation except the real interest rate and the inflation rate.

Table 2
Augmented Dickey Fuller (ADF) and Phillips-Perron (PP) Unit Root Tests.

	ADF		PP test	
	Level	1st Differenced	Level	1st Differenced
Log of Total Young to total population (*LYOUNG*)	-1.87	-4.12***	-1.30	-4.05***
	(T,1)	(c,0)	(T)	(c)
Log Total Working to total population (*LWORKING*)	-1.41	-2.87*	-0.48	-2.99**
	(T,2)	(c,0)	(T)	(c)
Log Total Old to total population (*LOLD*)	-2.34	-2.92**	-2.22	-2.77*
	(T,1)	(c,1)	(T)	(c)
Log of Saving to Gross Domestic Product (*LSAV*)	-2.89	-6.80***	-2.89	-7.48***
	(T,0)	(c,0)	(T)	(c)
Log of investment to Gross Domestic Product (*LINV*)	-2.64	-7.80***	-2.58	-12.28***
	(c,0)	(c,0)	(c)	(c)
Log of Real Gross Domestic Product (*LRGDP*)	-0.8	-4.29***	-0.75	-4.20***
	(T,0)	(c,0)	(T)	(c)
Log of Capital Stock(*LK*)	-1.52	-4.67***	-1.52	-4.62***
	(T,1)	(c,0)	(T)	(c)
Log of Employment * Human Capital (*LLH*)	-0.02	-3.52***	-0.04	-3.56*
	(T,0)	(c,0)	(T)	(c)
Log of Social Expenditure (*LSE*)	-0.32	-7.27***	-0.05	-7.27***
	(T,2)	(c,0)	(T)	(c)
Log of non -Fiscal Balance (*LNFB*)	-2.45	-13.46***	-2.05	-15.54***
	(c,2)	(c,0)	(c)	(c)
Inflation (*INF*)	-5.10***		-5.11***	
	(c,0)		(c,0)	
Real interest rate (*IR*)	-4.02***		-4.02***	
	(c,0)		(c,0)	

Notes: *, **, *** indicate statistical significance at 10%, 5% and 1% levels, respectively. The modified Akaike is used in the ADF test to determine the optimal lag length. For PP test, the truncation lags of the variables used to obtain white-noise residuals are determined by using *Newey-West Bandwidth.* The codes in parentheses below each test statistic indicate whether a trend is included (T) or only a constant (c) and the second entry is the number of lags in the ADF test equation.

5. Results

The test statistics used to determine the order of integration of each variable are the Augmented Dicky-Fuller (ADF) and Phillips Perron (PP) tests. Both test statistics test the null of a unit root against the alternative of stationarity. Table 2 shows that none of the variables appears to be integrated at an order higher than one, allowing the legitimate use of the ARDL test procedure.

To perform the bootstrap conditional ARDL test, an ECM is estimated with a maximum of four lags for each equation. The optimal lag length is chosen by the Akaike Information Criterion (AIC). Insignificant variables and lags are eliminated using the general-to-specific modelling approach. This explains why some estimated equations contain only a small number of explanatory variables. The final specification must pass various residual tests such as the correlogram *Q*-statistics, the Breusch-Godfrey *LM* test, and the Jarque-Bera test statistic (JB) for normality. One-off dummies are added in the estimation to capture exogenous shocks. The dummy is equal to one in the identified year and zero otherwise. Table 3 reports the estimates of each ARDL equation with the values of the three cointegration test statistics, the bootstrap critical values, and the diagnostic tests. All the regression specifications fit remarkably well with R^2 more than 0.7, and pass the diagnostic tests against non-normal residuals and serial correlation. The calculated *F*-test statistic for the lagged levels of all variables, the *t*-test statistic on the lagged level of the dependent variable, and the *F*-test statistic on the lagged levels of the independent variables are all significant at the 0.10 level or less compared with the critical values generated from the bootstrap procedure (see the last column of Table 3). This implies that the null hypothesis of no cointegration is rejected in every equation. The findings of cointegration imply that there is a long-run relationship between the dependent variable and the independent variables in each equation, which supports the theoretical framework discussed earlier.

Given the emphasis on the long-run relations, the remaining discussion focuses on the long-run coefficient estimates shown in Table 4. To be more specific, the long run estimates in Table 4 are based on the conditional ECM in Table 3, and all coefficients in the long-run equations are significant at least at the 5% level or less.[9] The estimated production function confirms that the real capital stock (*K*) and human capital augmented employment (*LH*) have positive influences on the level of real GDP in Taiwan with increasing returns to scale. This is because a one percent increase in *K* leads to a 0.47% increase in real GDP, whereas a one percent increase in *LH* would increase real GDP by close to one percent, which suggests that *LH* is a more fundamental source of Taiwan's real GDP growth in the long run. Correspondingly, a one percent increase in the level university education (*UNI*) would raise *LH* by 0.37% points, implying the level of *UNI* is an important driver of *LH* in the long run.

On the other hand, real GDP also has a positive and significant impact on real capital stock, gross domestic investment, gross domestic saving and the fiscal balance net of social expenditure in the long run. For instance, the estimation results show that a one percent increase in real GDP would result in a 1.07% increase in real capital stock (see row 2 in Table 4), implying the business sector responds strongly to economic growth with high capital outlays in the long run. Moreover, it appears that the magnitude of the increase in gross domestic investment (0.08%) is less than the increase in gross domestic saving (0.57%) for each one percent increase is real GDP (see rows 4 and 5 in Table 4). This implies that sustaining the growth in investment driven by overall economic growth necessitates net investment inflows from abroad. Similarly, a one percent increase in real GDP increases the fiscal balance net of social expenditure by 0.14% point (see row 7 in Table 4). Therefore, economic growth raises tax revenues to reduce possible fiscal deficits from increased spending on social expenditures driven by population aging.

Moreover, the long-run estimation results also reveal that the demographic variables significantly affect, gross domestic saving, and government social expenditures (see rows 4, 5 and 6 in Table 4, respectively). For example, the estimates of Eq. (5) corroborate the life-cycle hypothesis (LCH) that gross domestic saving is inversely related to both the old-age population (*LOLD*) and youth population (*LYOUNG*) ratios. One percentage point increases in elderly and youth population shares would decrease the gross domestic saving rate by 1.29% and 2.24% points in the long run. Besides, the demographic variables could also positively influence government social expenditures. Eq. (6) shows that one percent increases in *OLD* as well as *YOUNG* would lead to increases in government social expenditures by 1.36% and 1.5%, respectively. This confirms the hypothesis that increases in the proportion of elderly and youth

[9] Standard errors are computed by the delta method.

Table 3
The Augmented ARDL.

Estimated equations	Test statistics	Bootstrap CV		
		10 %	5 %	1 %
The Production Function				
$\Delta LRGDP_t = \underset{(0.44)}{1.12} - \underset{(0.07)}{0.28}LRGDP_{t-1} + \underset{(0.04)}{0.13}LK_{t-1} + \underset{(0.11)}{0.27}LLH_{t-1} + \underset{(0.13)}{0.64}\Delta LRGDP_{t-1} + \underset{(0.12)}{0.52}\Delta LRGDP_{t-3}$	F_1: 6.85**			
	t: -3.85***	5.38	6.59	9.56
$+ \underset{(0.11)}{0.53}\Delta LRGDP_{t-4} - \underset{(0.27)}{2.06}\Delta LLH_{t-1} - \underset{(0.24)}{1.16}\Delta LLH_{t-3} - \underset{(0.30)}{0.37}\Delta LLH_{t-4} + \underset{(0.08)}{0.17}\Delta LK_t$	F_2: 8.76**	-0.79	-1.21	-2.08
	N = 50;	6.92	8.72	12.80
$+ \underset{(0.22)}{2.42}\Delta LLH_t - \underset{(0.01)}{0.06}dum73 + \underset{(0.01)}{0.06}dum78 - \underset{(0.01)}{0.03}dum82 + \underset{(0.01)}{0.03}dum71 - \underset{(0.02)}{0.04}dum79$	R^2=0.94;			
$- \underset{(0.01)}{0.03}dum08 - \underset{(0.01)}{0.03}dum91 + \underset{(0.01)}{0.02}dum95 - \underset{(0.01)}{0.02}dum15 + \underset{(0.01)}{0.02}dum84$	Q(12) = 9.63 (0.64);			
	LM(2) = 2.10 (0.14);			
	JB = 0.28 (0.86)			
Employment & Human Capital				
$\Delta LLH_t = \underset{(0.02)}{0.086} - \underset{(0.00)}{0.03}LLH_{t-1} + \underset{(0.00)}{0.01}LUNI_{t-1} + \underset{(0.05)}{0.23}\Delta LLH_{t-1} + \underset{(0.07)}{0.34}\Delta LVOC_{t-2} + \underset{(0.06)}{0.36}\Delta LVOC_{t-3}$	F_1: 7.41***			
	t: -3.83***	3.86	4.79	7.30
$+ \underset{(0.02)}{0.22}\Delta LUNI_{t-2} - \underset{(0.02)}{0.13}\Delta LUNI_{t-3} - \underset{(0.02)}{0.09}\Delta LUNI_t - \underset{(0.10)}{0.20}\Delta LVOC_t - \underset{(0.00)}{0.01}dum01 - \underset{(0.00)}{0.02}dum09$	F_2: 3.08*	-1.18	-1.54	-2.22
$+ \underset{(0.00)}{0.03}dum86 - \underset{(0.00)}{0.00}dum90 - \underset{(0.00)}{0.00}dum85 + \underset{(0.00)}{0.01}dum91 + \underset{(0.00)}{0.01}dum04 + \underset{(0.00)}{0.00}dum11$	N = 40;	5.04	6.25	9.52
	R^2 = 0.98;			
$+ \underset{(0.00)}{0.00}dum10 - \underset{(0.00)}{0.00}dum00 - \underset{(0.00)}{0.00}dum99$	Q(12) = 15.56 (0.21);			
	LM(2) = 4.71 (0.10);			
	JB = 3.05(0.21)			
Capital Stock				
$\Delta LK_t = - \underset{(0.05)}{0.12} - \underset{(0.02)}{0.12}LK_{t-1} + \underset{(0.02)}{0.12}LRGDP_{t-1} + \underset{(0.10)}{0.19}\Delta LK_{t-1} - \underset{(0.01)}{0.04}dum94 - \underset{(0.01)}{0.06}dum83$	F_1: 16.25***			
	t: - 5.33***			
$- \underset{(0.01)}{0.06}dum10 - \underset{(0.01)}{0.04}dum91$	F_2: 5.33**	4.23	5.38	7.98
	N=58;	-1.37	-1.78	-2.78
	R^2 = 0.674;	5.05	6.55	7.18
	Q-stat(12)=7.9 (0.793);			
	LM(2) = 0.82 (0.44);			
	JB = 9.30 (0.69)			

(continued on next page)

Table 3 (*continued*)

Estimated equations	Test statistics	Bootstrap CV		
		10 %	5 %	1 %
Gross Domestic Investment				
$\Delta LINV = \underset{(0.36)}{1.06} - \underset{(0.08)}{0.61}LINV_{t-1} - \underset{(0.00)}{0.01}RLEN_{t-1} + \underset{(0.02)}{0.05}LRGDP_{t-1} - \underset{(0.08)}{0.24}\Delta LINV_{t-3} + \underset{(0.32)}{1.33}\Delta LRGDP_{t-1}$	F_1: 33.91***			
$+\underset{(0.34)}{1.23}\Delta LRGDP_{t-3} + \underset{(0.32)}{0.84}\Delta LRGDP_{t-4} + \underset{(2.03)}{3.66}\Delta LWORKING + \underset{(0.00)}{0.01}\Delta RLEN_{t-1} + \underset{(0.00)}{0.01}\Delta RLEN_{t-4}$	t: -7.58***	4.29	5.00	9.18
$+\underset{(0.07)}{0.22}dum04 - \underset{(0.06)}{0.19}dum09 - \underset{(0.06)}{0.21}dum85 + \underset{(0.06)}{0.24}dum74 - \underset{(0.06)}{0.14}dum01$	F_2: 10.19**	-2.42	-2.80	-3.74
	N = 54,	4.70	6.00	11.69
	R^2 = 0.81,			
	Q-stat(12) = 15.21 (0.21),			
	LM(2) = 0.93 (0.38), JB = 0.91 (0.62)			
Fiscal Balance Net of Social Expenditure				
$\Delta LNFB_t = \underset{(0.43)}{0.11} - \underset{(0.09)}{0.81}LNFB_{t-1} + \underset{(0.02)}{0.11}LRGDP_{t-1} - \underset{(0.05)}{0.15}\Delta LNFB_{t-1} + \underset{(0.04)}{0.19}\Delta LNFB_{t-3}$	F_1: 44.90***			
$+\underset{(0.61)}{2.95}\Delta LRGDP_{t-1}$	t: - 8.70***			
$+\underset{(0.00)}{0.00}\Delta INF_{t-2} - \underset{(0.64)}{1.86}\Delta LRGDP_t - \underset{(0.10)}{1.36}dum89 + - \underset{(0.13)}{0.67}dum93 - \underset{(0.10)}{0.23}dum95 - \underset{(0.10)}{0.41}dum09$	F_2: 17.64*	2.29	2.95	4.55
$-\underset{(0.11)}{0.31}dum01 + \underset{(0.10)}{0.30}dum98 + \underset{(0.10)}{0.29}dum00 - \underset{(0.10)}{0.23}dum08 + \underset{(0.10)}{0.23}dum84$	N = 50, R^2 = 0.95,	-1.93	-2.32	-3.09
	Q-stat(12) = 14.94 (0.24),	2.04	2.78	4.58
	LM(2) = 4.14 (0.12),			
	JB = 3.35 (0.18)			
Social Expenditure				
$\Delta LSE_t = -\underset{(0.83)}{2.28} - \underset{(0.06)}{0.38}LSE_{t-1} + \underset{(0.16)}{0.52}LOLD_{t-1} + \underset{(0.20)}{0.57}LYOUNG_{t-1} + \underset{(0.05)}{0.13}\Delta LSE_{t-3} - \underset{(0.98)}{2.73}\Delta LOLD_{t-2}$	F_1: 15.58***			
$+\underset{(0.95)}{3.11}\Delta LOLD_{t-4} - \underset{(1.16)}{2.42}\Delta LYOUNG_{t-1} + \underset{(1.03)}{4.02}\Delta LOLD_t - \underset{(1.50)}{2.61}\Delta LYOUNG_t + \underset{(0.04)}{0.48}dum00$	t: -5.66***			
$-\underset{(0.04)}{0.24}dum74 + \underset{(0.04)}{0.20}dum82 - \underset{(0.04)}{0.10}dum87 - \underset{(0.04)}{0.08}dum79 + \underset{(0.04)}{0.08}dum09 + \underset{(0.05)}{0.09}dum81$	F_2: 6.12*	6.18	7.69	11.44
$+\underset{(0.04)}{0.14}dum89$	N = 50,	-2.57	-3.01	-3.79
	R^2 = 0.89,	6.07	7.06	8.67
	Q-stat(12) = 5.77 (0.92),			
	LM(2) = 0.80 (0.66),			
	JB = 2.13 (0.34)			

(*continued on next page*)

Table 3 (*continued*)

Estimated equations	Test statistics	Bootstrap CV		
		10 %	5 %	1 %
Gross Domestic Savings				
$\Delta LSAV_t = \underset{(0.23)}{1.76} - \underset{(0.05)}{0.39}LSAV_{t-1} + \underset{(0.03)}{0.22}LRGDP_{t-1} - \underset{(0.10)}{0.87}LOLD_{t-1} - \underset{(0.06)}{0.50}LYOUNG_{t-1} - \underset{(0.00)}{0.00}INF_{t-1}$	F_1: 28.06***			
$- \underset{(0.15)}{0.74}\Delta LRGD_{t-1} - \underset{(0.13)}{0.76}\Delta LRGDP_{t-2} + \underset{(0.47)}{2.67}\Delta LOLD_{t-1} - \underset{(0.00)}{0.00}\Delta INF_{t-3} + \underset{(0.14)}{0.55}\Delta LRGDP_t$	t: -4.84***			
$+ \underset{(0.02)}{0.12}\text{dum86} - \underset{(0.02)}{0.04}\text{dum92} + \underset{(0.02)}{0.05}\text{dum06} - \underset{(0.02)}{0.05}\text{dum68} + \underset{(0.02)}{0.04}\text{dum73}$	F_2: 17.98***	12.04	14.80	16.78
	N = 55,	-2.67	-3.10	-3.98
	R^2 = 0.92,	14.80	15.40	16.60
	Q-stat(12)=13.32 (0.34),			
	LM(2) = 4.32 (0.66),			
	JB = 1.27 (0.5)			

Notes: Standard errors of estimated coefficients are reported in parentheses; *, **, *** indicate statistical significance at 10 %, 5 % and 1 % levels, respectively. F-statistics are the statistics for testing H_0: $\hat{\phi} = \hat{\gamma} = \hat{\varphi} = 0$, against H_1: $\hat{\phi}, \hat{\gamma}, \hat{\varphi} \neq 0$; t-statistics (lagged DV) are for tests on the lagged level of the dependent variable: H_0: $\hat{\phi} = 0$ against H_0: $\hat{\phi} < 0$; F-statistic (lagged IDV) is the statistic for testing on the independent variables: H_0: $\gamma = \varphi = 0$ against H_1: $\gamma, \varphi \neq 0$. N is the sample size. Q-stat (12) denotes Q statistic with 12 lags, LM(2) denotes the Breusch-Godfrey Lagrange Multiplier test statistic with 2 lags, JB indicates Jarque-Bera statistic for normality test. The values in parentheses are p values. Dummy variables D## are defined as one at the specific year ## and zero otherwise. For instance, D09 is specified as 1 at year 2009 and 0 for other years.

Table 4
Long-run equilibrium relationships implied by UECM.

1. Production function: $LRGDP_t = \underset{(0.12)}{0.47}LK_t^{***} + \underset{(0.24)}{0.97}LLH_t^{***}$

2. Real capital stock: $LK_t = \underset{(0.02)}{1.07}LRGDP_t^{***}$

3. Human capital employment: $LLH_t = \underset{(0.06)}{0.37}LUNI_t^{***}$

4. Gross Domestic Investment: $LINV_t = \underset{(0.03)}{0.08}LRGDP_t^{***} - \underset{(0.005)}{0.02}RLEN_t^{***}$

5. Gross Domestic Saving: $LSAV_t = \underset{(0.06)}{0.57}LRGDP_t^{***} - \underset{(0.15)}{1.29}LYOUNG_t^{***} - \underset{(0.23)}{2.24}LOLD_t^{***} - \underset{(0.00)}{0.01}INF_t^{***}$

6. Government Social Expenditure: $LSE_t = \underset{(0.27)}{1.36}LOLD_t^{***} + \underset{(0.36)}{1.50}LYOUNG_t^{***}$

7. Government Net Fiscal Balance: $LNFB_t = \underset{(0.036)}{0.140}LRGDP_t^{***}$

populations put upward pressure on the budget for age-related government social expenditures such as social benefits, public pensions, health care and education.

Since cointegration holds for the estimated equations, the system of ARDL equations is suitable for in-sample and out-of-sample simulations and long-run conditional forecasts (Goh et al., 2020). Population projection data from the United Nations (UN) are used to perform out-of-sample forecasts through 2040 for the key macroeconomic variables of Taiwan. These projections are based on the UN's medium-fertility variant.

Fig. 2 shows the out-of-sample[10] conditional forecast plots for Taiwan's key demographic and macroeconomic variables using the population projections from the UN. A notable feature of the plot for *LWORKING* is the declining size of the workforce throughout the forecast horizon, demonstrating the demographic shifts from population aging (see also the trajectories for *LOLD* and *LYOUNG*) due to low fertility rates in Taiwan. However, Taiwan's projected real GDP growth over the next one and a half decades (i.e., from 2020 to 2035) continues to be positive, even though the share of the working-age population declines persistently over the forecast period. What accounts for the positive real GDP growth through 2035 despite the declining working-age population in Taiwan is the steady increase in human capital (see the positive projections for *LH*). Investments in education at all levels have been and continue to be instrumental in expanding the capabilities of the labor force to meet the changing work environment and the market demands of tomorrow for sustainable growth. Another driving force behind continued economic growth in Taiwan is the accumulation of physical capital (see the continued growth in real capital stock, K, throughout the projection period) which requires a high gross saving rate and may also be driven by an increasingly costly skilled labor force. Despite the growth in human and physical capital throughout the projection period, real GDP turns down after 2035, reflecting diminished rates of growth in the two inputs and the complex dynamic process of the ARDL equation system. Amid super-aging in Taiwan, a shortage of

[10] Due to space constraint, we do not show the in-sample plot. The in-sample simulated values track the historical values closely.

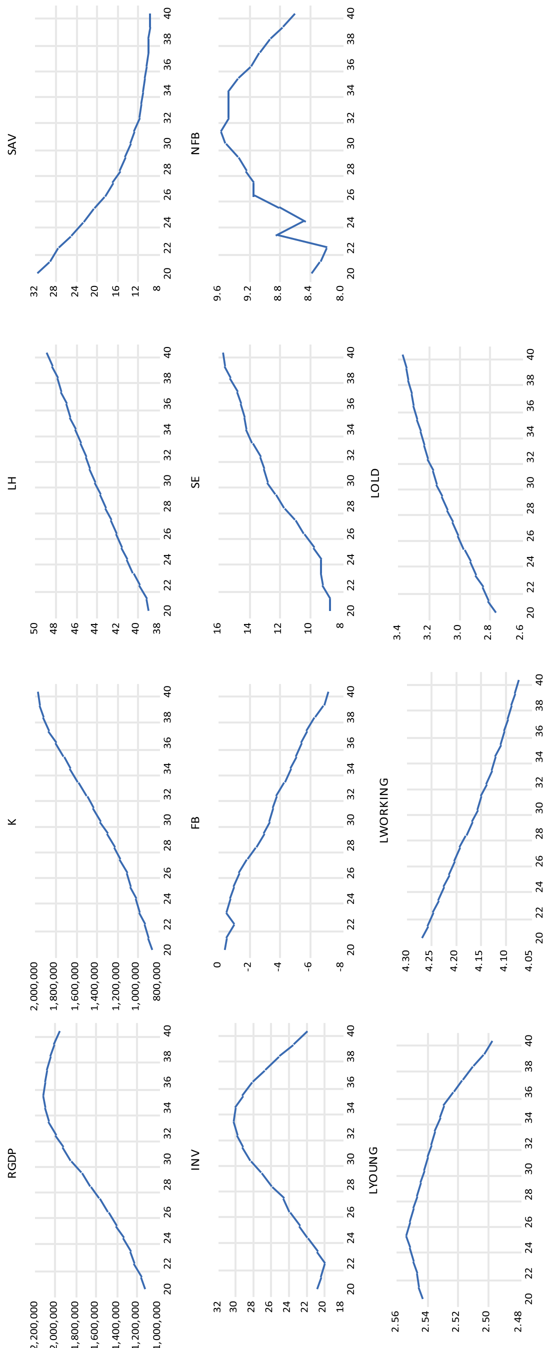

Figure 2. Out-of-sample forecast.

skilled workers emerges and the slowing growth rate of physical capital is unable to sustain positive gains in real output.

In addition, the projections show the negative effect of population aging on the ratio of gross domestic saving to gross domestic product (*SAV*) in the long run (i.e., the projected *SAV* becomes the mirror image of the projected *LOLD*). In addition, the growth in the elderly cohort (*LOLD*) will pose severe challenges to fiscal health in the long run in the context of shrinking working population (and hence, lower income tax revenue) and increasing the age-related government social expenditures (*SE*). As such, the fiscal balance (*FB*) is projected to be in deficit from 2020 to 2040. Graphically, the projected *FB* is a mirror image of *SE*, which is driven by *LOLD* and *LYOUNG*, and inevitably poses a challenge to fiscal sustainability as population aging continues.

6. Policy response

To mitigate the adverse macroeconomic effects of the declining working-age population and related population aging, the Taiwanese government should leverage the gradual retirement scheme. In effect, delayed retirement would create a stopgap that would prolong the working lives of the senior workers, which in turn could improve the financial wellbeing for the elderly during retirement. To protect middle-aged (between 45 and 65) and senior employees (above 65) from age discrimination in hiring, compensation and employment benefits, employers are liable to a hefty fine under the Middle-Aged and Elderly Employment Promotion Act that was effective in 2020[11] if they are found guilty of practicing age discrimination. To promote diversity and inclusion, employers should be rewarded with generous tax deductions for hiring, retaining, retraining, and rehiring of middle-aged and senior employees. Keeping experienced middle-aged and senior workers on the job would not only be a source of economic growth but also a vital source of tax revenue to fund the age-related government social expenditures of the expanding elderly population. Thus, promoting the employment of older workers and extending the working lives of senior workers are instrumental in reducing the public expenditure on the support of the elderly. Increasing their working lives would also enhance personal saving of the elderly, leading to a higher aggregate saving rate to fund increased investment.

In the longer run, countervailing measures are necessary to contend with the shrinking workforce, which is an inevitable macroeconomic outcome of demographic aging process. The best policy response for the Taiwanese economy is to capitalize on its human capital by re-engineering production processes to embrace high technology. The switch to high capital-intensive production in place of a shrinking workforce remains the best path to sustainable growth. There is no reason to believe Taiwan’s growth will abate by changing the composition of production inputs with an increase in capital intensity. Advanced technologies embodied in modern capital equipment and electronics will contribute to ever higher levels of productivity and total output. To facilitate the shift of local firms into high value-added and high technology-based industries, the Taiwanese government should provide matching grants (which would be funded from the fiscal budget) to assist capable local firms make the quantum leap in acquiring emerging technologies for the production of high value-added products. In order to support the shift towards the high-value-added and high technology activities, the Taiwanese government

[11] https://www.globalcompliancenews.com/2021/01/31/taiwan-middle-aged-and-senior-aged-employment-promotion-act-came-into-force-to-facilitate-employment-of-senior-workforce-14122020/

should promote foreign direct investment and joint ventures between local firms and foreign multinationals, to increase the intake of skilled immigrants, to upgrade the physical and technology infrastructure, and to develop worker training programs focusing on skills and technologies needed by modern industries.

7. Conclusions

Faced with the aging labor force and population trends, Taiwan is poised to become a super-aged society in 2025 when its population above the age of 65 constitutes 20% of the entire population. As a consequence, this could pose a major challenge to Taiwan's future economic growth because population aging will continue as a result of declining fertility and increasing life expectancy. The most obvious adverse impact of ageing is the expected decline in the share of the working-age population, with a growing labor shortage in Taiwan impinging on economic growth in the future.

The empirical analysis in this study adds several important insights into the economic implications of aging societies. First, ARDL tests of cointegration establish the existence of long-run equations that relate key macroeconomic variables to changing demographic forces, as represented by population age shares for youths, working-age people, and the elderly. Second, Taiwan's total output is driven, first and foremost by the quality of labor input, and by physical capital in an aggregate production function that exhibits increasing returns to scale. The quality of labor input is essential to understand Taiwan's success, in which sustained economic growth has been and can continue to be, the result of increasing human capital. The increasing quality of labor input, driven by the highest educational attainment at the tertiary level, compensates for the declining share of the working-age population to sustain real GDP growth in the long run. Third, real GDP growth is instrumental in encouraging saving and investment and tends to improve the fiscal balance net of social expenditures in the long run. Fourth, a labor shortage stemming from a reduction in the share of the working-age population leads to an increased demand for the capital input to offset the shrinking labor supply. Finally, Taiwan can expect to see worsening imbalances between overall saving and investment, including those of the public sector. The empirical estimates indicate that increases in the population age shares of the young and old age categories reduce the aggregate saving ratio as predicted by the life cycle saving hypothesis. At the same time, age-related government social expenditures are expected to increase with both youth and elderly population ratios.

The long run implications of these empirical findings are explored further through out-of-sample projections of the demographic and macroeconomic variables out to 2040. First, the real GDP is projected to continue growing for at least for a decade or more. Strategies for investments in human and physical capital are able to sustain positive growth in the face of a declining workforce until 2035, when the pressures of labor shortages become too severe. This argues for consideration of other policies that can alleviate the worker shortage, namely raising the retirement age of future cohorts of workers, enforcing policies against age discrimination in the workplace, promoting greater incentives through pay and benefits for older workers, and increasing the intake of skilled immigrants. These policies would not only compensate directly for the shortage of younger workers and the native born, but could also ameliorate pending fiscal imbalances. Delayed retirement may not only encourage higher participation rates of the elderly and provide extra income to future generations of older workers, but also increase their propensities to save. Increasing the number of skilled migrants of working age would also contribute tax revenues to ease looming fiscal pressures stemming from the need to support larger cohorts of older people. Correcting gross saving-investment imbalances would also ameliorate a growing current account deficit. Of course, these additional policies would be additions to, not substitutes for, investments in human capital that have been the primary engine of Taiwan's economic success so far.

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