How South Korea Escaped from the Malthusian Trap: Evidence from the Galor-Weil Model

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This study analyzes how South Korea escaped the Malthusian trap using the Galor-Weil (2000) model. This study contributes to the literature on two points. First, it categorizes the education that enables quantity-quality tradeoffs into secondary and tertiary education. Second, this model was analyzed for the first time in South Korea. According to the empirical findings, education reduces fertility and mortality rates, but tertiary education is necessary for technological progress. South Korean society has changed its structure from quantity to quality and escaped the Malthusian trap as a consequence of its education policies.

Keywords: Malthusian Trap, Quantity-Quality tradeoff, Economic Growth

JEL Classification: J13, I25, F63

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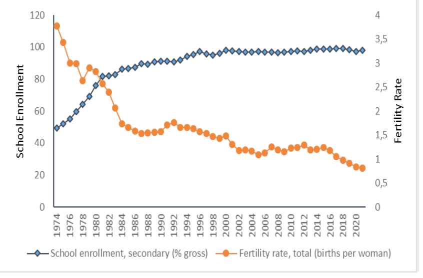
[**Seoul Journal of Economics** 2024, Vol. 37, No. 4]
DOI: 10.22904/sje.2024.37.4.002

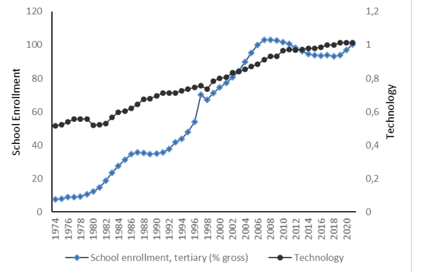
I. Introduction

According to Malthus (1872), an increase in production will not be sufficient for population growth. Therefore, countries cannot escape the Malthusian trap unless output growth is higher than population growth. Galor and Weil (2000) argue that escape from the Malthusian trap can be achieved through quantity-quality tradeoffs and that an improvement in education can enable the achievement of quantity-quality tradeoffs in the population. The quantity-quality tradeoff also accelerates technological progress. This acceleration in technology has a positive impact on output. Countries cannot escape this trap if welfare increases fertility. According to them, parents should change their choices from the number of children to their quality to escape from this trap.

Moreover, continuous improvement in the educational level of human capital increases the effectiveness of technology. Therefore, technological development and human capital proceed in harmony. In this process, a conscious society and improvements in the field of health due to technological development cause a decrease in newborn mortality rates. The quantity-quality tradeoff in society and the decline in newborn mortality rates have a negative impact on fertility. Hence, if the quantity-quality tradeoff is realized and technological progress continues, economic growth quantitatively and qualitatively increases. However, not all countries achieve this transformation in the same way. Countries that achieve this tradeoff escape the Malthusian trap. Education and technology, which are the basic dynamics of growth, determine the growth trends of countries. The best example of a country that has escaped this trap and achieved a miracle is South Korea (Moo-Ki, 1982; Moskowitz, 1982; Dornbusch and Park, 1987; Collins, 1990; Piazolo, 1995; Kwon, 1997; Hwang, 1998; Choe and Moosa, 1998; Oh, 1999; Yuhn and Kwon, 2000; Lee, 2007; Chung, 2011).

South Korea was a poor country, newly liberated from Japanese colonization in 1945. It was economically dependent on foreign countries and had a small manufacturing sector. Famine and epidemics were spread across the country. The country was caught in a cycle of wars and economic crises. The first action taken to realize the miracle and escape from this trap was a radical reform of the education system. By the 1970s, the results of the government policy that preferred quality rather than quantity in population began to be observed concretely. A





(Based on World Bank 2024 data.)

FIGURE 1

1A (LEFT) AND 1B (RIGHT): SECONDARY EDUCATION EDUCATION AND FERTILITY RATE - TERTIARY EDUCATION EDUCATION AND TECHNOLOGY

demographic transformation was achieved in this process. The share of the tertiary educated labor force increased, the fertility rate decreased, and technology became the fundamental element of development plans. This transformation is clearly outlined in Figures 1a and 1b.

Figure 1a shows a negative relationship between the second level of schooling, which refers to secondary education, and fertility. After the success in the schooling rate, the progress achieved in the level of education triggered technological progress, as shown in Figure 1b. Technological progress doubled its performance with the increase in tertiary education. Both figures show that South Korea increased its human force, experienced technological progress acceleration, and transformed its labor force from quantity to quality over the years.

Considering all these factors, it can be argued that South Korea started to escape from the Malthusian trap in the 1970s. This claim is one of the main motivations of this study. Another motivation for this study is to test the validity of the South Korean miracle based on the Galor-Weil (2000) model. Based on these main motivations, the study aims to empirically test how South Korea has escaped from the Malthusian trap using the Galor-Weil (2000) model.

In this framework, this study contributes to the literature on the Malthusian trap on two points. First, South Korea's escape from the Malthusian trap is examined for the first time. Second, this study considers the level of education in two ways: secondary and tertiary education. According to Galor-Weil (2000), technology gains a positive momentum as society changes from quality to quantity and turns to education. However, the level of education needs to increase to continue this acceleration and work the human capital in harmony with the developing technology. Therefore, categorizing the level of education into secondary and tertiary provides a clearer picture of the effects of education on demographic transformation and technological progress. Following this introduction, the rest of the paper is structured as follows. Section 2 briefly reviews the literature on the growth model of Galor and Weil (2000) and empirical studies related to the model. Section 3 presents the research methodology and data. Empirical results are presented and discussed in Section 4, followed by conclusions and policy implications in Section 5.

II. THEORETICAL BACKGROUND

All growth models are based on the definition of aggregate output in an economy by an aggregate production function. In all pre-industrial economies and many poor countries in the world today, this function has two basic inputs: land and labor. Hence, the growth function of the Malthusian model is as follows:

$$Y = AX^{\alpha}L^{1-\alpha} \qquad 0 < \alpha < 1, \tag{1}$$

where Y represents total output, A represents the technology change parameter, X represents the fixed amount of land, and L represents the total labor force in the economy. In the equation, parameter α denotes the output elasticity of land and $(1 - \alpha)$ denotes the output elasticity of labor. Based on this information, the marginal product of labor is defined in Equation (2):

$$\frac{\partial Y}{\partial L} = (1-\alpha)AX^{\alpha}L^{-\alpha} = (1-\alpha)A\left(\frac{X}{L}\right)^{\alpha} > 0. \tag{2}$$

The marginal product of labor is always positive. However, under the assumption of the law of diminishing returns, the positive effect of each additional increase in L is always smaller than the previous one, which implies a quadratic derivative of Y with respect to L as shown in Equation (3):

$$\frac{\partial^2 Y}{\partial L^2} = -\alpha(1-\alpha)AX^{\alpha}L^{-\alpha-1} < 0. \tag{3}$$

If the relationship between output and inputs is redefined per labor force, Equation (4) is obtained:

$$y \equiv \frac{Y}{L} = \frac{AX^{\alpha}L^{1-\alpha}}{L} = \frac{AX^{\alpha}}{L^{\alpha}} \cdot \frac{L}{L} = A\left(\frac{X}{L}\right)^{\alpha} = Ax^{\alpha}. \tag{4}$$

In this equation, $y\left(\equiv \frac{Y}{L}\right)$ is the output per labor force, and $x\left(\equiv \frac{Y}{L}\right)$ is the land per labor force. This new equation clearly shows that in the Malthusian model, output per labor force is decreased due to the increase in population.

$$\frac{\partial y}{\partial L} = -\alpha(1-\alpha)AX^{\alpha}L^{-\alpha-1} < 0, \quad \frac{\partial^2 y}{\partial L^2} = \alpha(1+\alpha)AX^{\alpha}L^{-\alpha-2} > 0. \tag{5}$$

The main feature of the Malthusian model is that output per capita is strongly negatively correlated with population growth, as shown in Equation (5). Hence, to explain the relationship between output per capita and population, the factors affecting population growth should also be explained. Equation (6) shows the population equation at time t:

$$L_t = L_{t-1} + B_t(y_{t-1}) - D_t(y_{t-1}). \tag{6}$$

In this equation, the population in period t (L_t) is determined by adding births in period t (B_t) and subtracting deaths (D_t) to the population in period $t - 1$.

According to Equation (6), B_t and D_t are functions of the previous year's output per labor force (y_{t-1}). The level of output per labor force in the previous year positively affects the birth rate [$B^t(y_{t-1}) > 0$] and negatively affects the death rate [$D^t(y_{t-1}) < 0$].

According to the model, a positive shock in the economy will positively affect the output per labor function. Therefore, output per labor force increases because the increase will have a positive effect on the birth rate and a negative effect on the mortality rate. Therefore, the increase in the population growth rate has a decreasing effect on the per capita ratio of the initial increase in output. As a result, output per labor force returns to its initial equilibrium level in the long run, while the only change in the economy is a change in the quantity of the labor force. This cycle is the Malthusian trap.

Galor and Weil (2000) extend the Malthusian model by adding education to express how countries can escape the Malthusian trap. The basic assumption of the Galor and Weil (2000) model is that families choose between the number of children and the education level of their children. Accordingly, the production function of Galor and Weil (2000) is as follows:

$$Y = H_t^{\alpha}\left(A_t X\right)^{1-\alpha} \qquad 0 < \alpha < 1. \tag{7}$$

In this equation, Y represents total output, H_t, X represents efficiency units of labor employed at time t and quantity of land, and $A_t > 0$ represents endogenously determined technological level at time t.

The utility function also changed as a result of the change in the priorities of individuals in the model. Parents divide their time between child-rearing and labor force participation. The time allocated to child-rearing is an optimal mixture of quantity and quality. Accordingly, the utility function in this new model of Galor and Weil (2000) is

$$u^t = \left(c_t\right)^{(1-\gamma)}\left(w_{t+1} n_t h_{t+1}\right)^{\gamma} \tag{8}$$

In Equation (8), $c_t\left(\equiv \frac{C_t}{L_t}\right)$ is per capita consumption, $n_t \geq 0$ is the number of children surviving after birth, $Y \in (0,1)$, h_{t+1} is the level of human capital of each child, and w_{t+1} is the wage per efficiency unit of labor at time $t+1$.

In the model, the cost of raising children in a family is divided into two parts: time allocated to basic childcare (τ) and time allocated to child education (τ^e). Assuming that the time allocated for a child's education in the next period is e_{t+1}, n_t denotes the total number of children of the family in period t, while the normalized total time allocated by families for their children is 1. Based on this information, the family's time constraint is as follows:

$$n_t(\tau + \tau^e e_{t+1}) \leq 1. \tag{9}$$

$n_t(\tau + \tau^e e_{t+1}) = 1$ individuals have to choose between the number of children and the education level of existing children.

The key element in breaking the Malthusian trap is the choice of education; that is, society's preference for quality rather than quantity. The critical point in the Malthusian trap is the answer to the question: “How do individuals maximize their limited income and utility between consumption and children, and do they focus on the quantity or quality of children in their limited time?”. In other words, a demographic transformation occurs.

$$\frac{\partial e_t}{\partial g_t} = e_g \geq 0, \qquad \frac{\partial^2 e_t}{\partial g_t^2} = e_{gg} \leq 0. \tag{10}$$

In Galor and Weil (2000), the optimal level of e_{t+1} is a function of technological progress ($e_t = e(g_t)$). The underlying logic is the belief that the higher the level of education in a society, the greater the pace of technological progress. The growth rate of technological knowledge is depicted as follows:

$$\frac{A_{t+1} - A_t}{A_t} = g_{t+1} = g(e_t L_t), \tag{11}$$

$$\frac{\partial g}{\partial e_t} = g_e \geq 0, \qquad \frac{\partial^2 g}{\partial e_t^2} = g_{ee} \leq 0$$

Therefore, positive feedback between e_t and g_t exists.1

Assuming that the population $L_0 > 0$, and the level of education $e' > 0$ at the beginning of an economy, significant growth in technological progress occurs in the following year ($e' > 0$). However, the level of education decrases if future education is not emphasized at this level g. At this low level of education (e'), technological progress slows down from g' to g'' ($g'' < g'$). This scenario is typical of the Malthusian trap. However, the increase in the level of education continues as a result of parents' preference for quality in period $t + 1$. Therefore, the increasing level of education continues to bring technological progress. To continue this technological progress, both the quality and quantity of human

[1] For the derivation equation, see Galor and Weil (2000).

capital need to increase. That is, according to the model, a certain level of education is initially necessary for technological progress to be realized up to a certain stage. However, to ensure continued increase of technological progress, the level of education should also increase. Galor-Weil (2000) refers to this situation as the erosion effect. A labor force with an insufficient education level cannot adapt to the developing technology, remains outside the production process, and technological development cannot be achieved because it is not equipped to continue technological development.

Therefore, the level of education needs to increase. Whether the level of education increases or remains constant is an indication that education is categorized within itself. The level of education necessary for technological progress to continue to increase is tertiary education (Krueger and Kumari, 2004; Aghion *et al.*, 2005; Bloom *et al.*, 2014; and Zhou and Luo, 2018). In examining the South Korean application of the model, we extended the model by categorizing it into secondary and tertiary education. The main expectation underlying this extension is that reduced fertility and mortality are outputs of secondary education, while continued technological progress is an output of tertiary education. A tertiary level of education enables faster technological progress, and the economy stabilizes at a higher level of education and technology. This process results in an escape from the Malthusian trap.

In the applied literature, very few studies use the Galor-Weil (2000) model to model the exit from the Malthusian trap. In these studies, Lagerlöf (2005) confirms the Galor-Weil (2000) hypothesis with empirical findings of his simulation on Western European countries between 0–1900. Mejía, D., *et al.* (2008), their empirical findings from VAR Analysis on Colombia between 1905–2005 confirm the Galor-Weil (2000) hypothesis. Elgin (2010) confirms the Galor-Weil (2000) hypothesis with the empirical findings obtained from the simulation on the UK between 1750–2000 . Madsen and Strulik (2023) confirm the Galor-Weil (2000) hypothesis in their 2SLS regression analysis on 21 OECD countries between 1750 and 2000. The studies are shaped in the long run and address whether societies could escape the Malthusian trap of technological progress triggered by demographic transformation.

III. DATA AND METHODOLOGY

The data set of the research is shown in Table 1.

TABLE 1
DATA INFORMATION TABLE

Symbol	Variable	Definition	Year	Source
pc1	GDP per capita growth	Annual growth rate of real income per capita	1974–2021	World Bank
g	Technology	Rate of growth in total factor productivity	1974–2021	Our World in Datan (Data for 2019–2021 are derived from the ARIMA method).
Fr	Fertility rate	Rate of growth in the birth rate per woman (percentage change from the previous year)	1974–2021	World Bank
Mr	Mortality rate	Growth rate in newborn mortality rate per 1000 births (percentage change from the previous year)	1974–2021	World Bank
sc(2)	School enrollment, secondary	Gross enrollment ratio for secondary school is calculated by dividing the number of students enrolled in secondary education regardless of age by the population of the age group, which officially corresponds to secondary education and multiplying by 100.	1974–2021	World Bank
sc(3)	School enrollment, tertiary	Gross enrollment ratio for tertiary schools is calculated by dividing the number of students enrolled in tertiary education regardless of age by the population of the age group which officially corresponds to tertiary education and multiplying by 100.	1974–2021	World Bank
Pg	Population growth	Difference in population growth rate compared to the previous year	1974–2021	World Bank

In the analysis, the base year is 1974, which represents the beginning of heavy and chemical industrialization because it requires human capital with higher levels of education and faster technological progress in this process (Piazolo, 1995). The latest data were officially published in 2021. Therefore, the period of analysis is 1974–2021. Additionally, the total factor productivity data were last published in 2019. Therefore, data for 2020–2021 are forecast with the ARIMA method.

TABLE 2
DESCRIPTIVE STATISTICS

Panel A: Data used for Galor-Weil Model in VAR Analysis							
	PCI	FR	MR	SC2	SC3	G	PG
Mean	5,49	-0,03	-0,05	0,01	0,05	0,01	0,85
Median	5,58	-0,03	-0,04	0,00	0,03	0,01	0,83
Maximum	11,71	0,10	0,26	0,09	0,26	0,06	1,68
Minimum	-5,81	-0,16	-0,43	-0,01	-0,04	-0,06	-0,17
Std. Dev.	3,86	0,06	0,12	0,02	0,07	0,02	0,44
Skewness	-0,49	0,08	-0,78	1,57	1,21	-0,64	0,16
Kurtosis	3,31	2,56	4,52	4,45	3,91	6,93	2,39
Jarque-Bera	2,13	0,43	9,37	23,62	13,16	33,55	0,93
Probability	0,34	0,80	0,00	0,00	0,00	0,00	0,93
Sum	258,15	-1,54	-2,61	0,68	2,59	0,67	39,98
Sum Sq. Dev.	687,37	0,18	0,74	0,03	0,24	0,02	9,17
Observations	47	47	47	47	47	47	47

Panel B: Data used for Determination of TFP in ARDL Bounds Test				
	G	SC2	SC3	PCI
Mean	-0,28	89,37	3,83	5,53
Median	-0,28	95,88	4,22	5,69
Maximum	0,01	99,31	4,63	11,7
Minimum	-0,66	49,50	2,01	-5,81
Std. Dev.	0,22	13,22	0,08	3,83
Skewness	-0,25	-1,80	-0,8	-0,52
Kurtosis	1,71	5,20	2,50	3,36
Jarque-Bera	3,80	35,83	6,75	2,51
Probability	0,14	0,00	0,00	0,28
Sum	-13,6	4290	184	265
Sum Sq. Dev.	2,46	8217	33,6	691
Observations	48	48	48	48

Descriptive statistics of the series used in the analysis are given in Table 2. Panel A shows the descriptive statistics of the series used in the VAR analysis. According to Panel A, the mean and median values are close, and thus, the series is reported to exhibit a symmetric distribution. Standard deviation values indicate the absence of excessive volatility in the series. According to the skewness and kurtosis results, PCI, MR, and G series are left-skewed, while FR, SC2, SC3, and PG series are right-skewed. The skewness of the SC2 and SC3 series is higher than the other series. The kurtosis of the PCI, MR, FR, SC2, SC3, and PG series is suitable for a normal distribution. The dispersion of the G series is higher than the required value. According to the Jarque-Bera test, all series are normally distributed. Panel B shows the descriptive statistics of the series used in the ARDL analysis. According to Panel B, the mean and median values are close, and therefore, the series is reported to be distributed symmetrically. No excessive volatility was observed in the other series except for the SC2 series. According to the skewness and kurtosis results, all series are left skewed. The symmetry of the G and PCI series is higher than SC2 and SC3. The kurtosis of the series conforms to the normal distribution. According to the Jarque-Bera test, all of the series conform to the normal distribution.

VAR analysis approach, Granger causality variance decomposition, and ARDL bounds tests are used to analyze the Galor-Weil(2000) model in detail and identify the long-run determinants of TFP.

The model for this study in VAR analysis is specified as

$$\Delta PCI_t = \alpha_{1t} + \sum_{i=1}^{n} \theta_{11} \Delta PCI_{t-i} + \sum_{i=1}^{n} \beta_{12} \Delta FR_{t-i} + \sum_{i=1}^{n} \gamma_{13} \Delta MR_{t-i} + \sum_{i=1}^{n} \sigma_{14} \Delta SC2_{t-i} + \sum_{i=1}^{n} \delta_{15} \Delta SC3_{t-i} + \sum_{i=1}^{n} \varphi_{16} \Delta G_{t-i} + \sum_{i=1}^{n} \omega_{17} \Delta PG_{t-i} + \varepsilon_{1t}$$

$$\Delta FR_t = \alpha_{2t} + \sum_{i=1}^{n} \theta_{21} \Delta PCI_{t-i} + \sum_{i=1}^{n} \beta_{22} \Delta FR_{t-i} + \sum_{i=1}^{n} \gamma_{23} \Delta MR_{t-i} + \sum_{i=1}^{n} \sigma_{24} \Delta SC2_{t-i} + \sum_{i=1}^{n} \delta_{25} \Delta SC3_{t-i} + \sum_{i=1}^{n} \varphi_{26} \Delta G_{t-i} + \sum_{i=1}^{n} \omega_{27} \Delta PG_{t-i} + \varepsilon_{2t}$$

$$\Delta MR_t = \alpha_{3t} + \sum_{i=1}^{n} \theta_{31} \Delta PCI_{t-i} + \sum_{i=1}^{n} \beta_{32} \Delta FR_{t-i} + \sum_{i=1}^{n} \gamma_{33} \Delta MR_{t-i} + \sum_{i=1}^{n} \sigma_{34} \Delta SC2_{t-i} + \sum_{i=1}^{n} \delta_{35} \Delta SC3_{t-i} + \sum_{i=1}^{n} \varphi_{36} \Delta G_{t-i} + \sum_{i=1}^{n} \omega_{37} \Delta PG_{t-i} + \varepsilon_{3t}$$

$$\Delta SC2_t = \alpha_{4t} + \sum_{i=1}^{n} \theta_{41} \Delta PCI_{t-i} + \sum_{i=1}^{n} \beta_{42} \Delta FR_{t-i} + \sum_{i=1}^{n} \gamma_{43} \Delta MR_{t-i} + \sum_{i=1}^{n} \sigma_{44} \Delta SC2_{t-i} + \sum_{i=1}^{n} \delta_{45} \Delta SC3_{t-i} + \sum_{i=1}^{n} \varphi_{46} \Delta G_{t-i} + \sum_{i=1}^{n} \omega_{47} \Delta PG_{t-i} + \varepsilon_{4t}$$

$$\Delta SC3_t = \alpha_{5t} + \sum_{i=1}^{n} \theta_{51} \Delta PCI_{t-i} + \sum_{i=1}^{n} \beta_{52} \Delta FR_{t-i} + \sum_{i=1}^{n} \gamma_{53} \Delta MR_{t-i} + \sum_{i=1}^{n} \sigma_{54} \Delta SC2_{t-i} + \sum_{i=1}^{n} \delta_{55} \Delta SC3_{t-i} + \sum_{i=1}^{n} \varphi_{56} \Delta G_{t-i} + \sum_{i=1}^{n} \omega_{57} \Delta PG_{t-i} + \varepsilon_{5t}$$

$$\Delta G_t = \alpha_{6t} + \sum_{i=1}^{n} \theta_{61} \Delta PCI_{t-i} + \sum_{i=1}^{n} \beta_{62} \Delta FR_{t-i} + \sum_{i=1}^{n} \gamma_{63} \Delta MR_{t-i} + \sum_{i=1}^{n} \sigma_{64} \Delta SC2_{t-i} + \sum_{i=1}^{n} \delta_{65} \Delta SC3_{t-i} + \sum_{i=1}^{n} \varphi_{66} \Delta G_{t-i} + \sum_{i=1}^{n} \omega_{67} \Delta PG_{t-i} + \varepsilon_{6t}$$

$$\Delta PG_t = \alpha_{7t} + \sum_{i=1}^{n} \theta_{71} \Delta PCI_{t-i} + \sum_{i=1}^{n} \beta_{72} \Delta FR_{t-i} + \sum_{i=1}^{n} \gamma_{73} \Delta MR_{t-i} + \sum_{i=1}^{n} \sigma_{74} \Delta SC2_{t-i} + \sum_{i=1}^{n} \delta_{75} \Delta SC3_{t-i} + \sum_{i=1}^{n} \varphi_{76} \Delta G_{t-i} + \sum_{i=1}^{n} \omega_{77} \Delta PG_{t-i} + \varepsilon_{7t}$$

In this specification, α_{1t}, α_{2t}, α_{3t}, α_{4t}, α_{5t}, α_{6t}, and α_{7t}, are constant terms. θ, β, γ, σ, δ, φ, and ω, represent the coefficients of the *PCI*, *FR*, *MR*, *SC*2, *SC*3, *G*, and *PG* series, respectively. ε_{1t}, ε_{2t}, ε_{3t}, ε_{4t}, ε_{5t}, ε_{6t}, and ε_{7t} are the error terms.

IV. ANALYSIS RESULTS

In time series analyses, the stationarity of the data is first checked using unit root tests. Augmented Dickey-Fuller (ADF) and Dickey-Fuller GLS (DF-GLS) tests are used for stationarity control. The results of the unit root tests are shown in Table 3.

According to the unit root test results shown in Table 3, all variables are stationary at the I(0) level. Secondary education, tertiary education, mortality rate, fertility rate, and technology data are growth rates (calculated by taking the differences of logarithmic series). Growth in per capita income and population growth series are annual percentage change data.

The vector autoregressive (VAR) method is applied in the analysis.

TABLE 3
UNIT ROOT TESTS

	Level			
	Fixed		Constant and Trend	
	ADF	DF-GLS	ADF	DF-GLS
Pci	-4,88***	-4.62***	-6,80***	-6,87***
G	-3.21**	-3,22***	-4,18***	-3,88***
Fr	-5,42***	-3,49***	-4,22***	4,08***
Mr	-5,29***	-3,47***	-5,16***	-5,33***
Sc(2)	-7,80***	-1,96**	-6,61***	-3,16*
Sc(3)	-4,09***	3,22***	-4,18***	3,88***
Pg	-6,83***	-6,84***	-6,76***	-6,72***

Notes: *, **, and *** denote stationary data at 10%, 5%, and 1% statistical significance levels, respectively. The appropriate lag length is determined according to the Schwarz Information Criterion.

Because the VAR model is widely used to model the temporal dependence of a multivariate time series, this method is used. The temporal dependence of a multivariate series includes the interdependence between different components. The VAR model is well suited to describe such temporal dependence structures (Davis *et al.*, 2016).

Then, the VAR model was formed, and the three conditions that must be met to perform Granger causality analysis were tested. According to the test results, the modulus values of the characteristic equation are within the unit root circle and are stationary. Moreover, the model does not contain changing variance at the 5% significance level and has a constant variance. Finally, the model does not have autocorrelation at the 5% significance level. According to these results, all three conditions of VAR analysis are met. In this case, the block exogeneity Wald test for Granger causality analysis can be performed as a result of the VAR model.

After the Granger Causality test, the variance decomposition test was performed with the VAR model. With this test, the explanation power of the variables on each other in the short and long run was obtained. Thus, it was possible to observe the changes in the explanatory power of the variables in the demographic transformation process of South Korea in more detail. As a result, the consistency of the analysis with

TABLE 4

GRANGER CAUSALITY TEST (BLOCK EXOGENEITY WALD TEST) RESULTS

mr	→	fr	12.19223***	A unidirectional Granger causality exists	A reduction in the newborn mortality rate has a negative effect on fertility because it increases the number of surviving children. This scenario is consistent with the Malthusian escape from the trap.
g	⇄	pc1	22.37872*** 21.73262***	A mutual Granger causality exists	An increase in technology has a positive effect on output, leading to an increase in people's incomes. An increase in growth in per capita income initially has a positive effect on technology.
e(2)	→	pc1	5.694400*	A unidirectional Granger causality exists	Increasing education at the secondary and tertiary levels increases growth in per capita income by increasing output through technology and reducing fertility. It supports the Galor-Weil (2000) theory.
e(3)	→	pc1	32.96473***	A unidirectional Granger causality exists	
mr	→	pc1	7.858099**	A unidirectional Granger causality exists	As mortality decreases, growth in per capita income decreases. This scenario is consistent with the Malthusian trap.
sc(2)	→	mr	4.886088*	A unidirectional Granger causality exists	An increase in the level of education leads to awareness of society and advances in the field of health with developing technologies. As a result, newborn mortality rates decrease. It is consistent with escape from the Malthusian trap.
sc(3)	→	mr	5.604144*	A unidirectional Granger causality exists	
sc(2)	→	g	26.95112***	A unidirectional Granger causality exists	According to the theory, secondary education initially accelerates the slow and insufficient progress in technology. In the following process, the increase in tertiary education accelerates the increase in technology as a result of the increasing demand for human capital to continue technological progress. Galor-Weil (2000) supports the theory.
sc(3)	→	g	36.74753***	A unidirectional Granger causality exists	
fr	→	g	8.444783**	A unidirectional Granger causality exists	Technological progress is gaining momentum as social preferences change from quantity to quality. It is consistent with escape from the Malthusian trap.
mr	→	g	13.04180***	A unidirectional Granger causality exists	The Granger causality of mortality rates for technology has no connection with the theory.

Note: *, **, and *** denote statistical significance at the 10%, 5%, and 1% levels, respectively.

Table 5

Variance Decomposition Test Results

	Period	PCI	FR	MR	SC2	SC3	G	PG
FR	1	19,17854	80,82146	0,000000	0,000000	0,000000	0,000000	0,000000
	2	14,50342	67,48622	14,77765	1,458347	0,622052	0,087872	1,064443
	3	12,19506	57,45340	12,88886	2,893312	6,276945	3,053932	5,238489
	4	12,03440	54,51153	12,47542	6,936947	5,923391	2,874663	5,243648
	5	11,38890	51,62070	12,04918	8,102853	7,766200	2,881326	6,190848
	6	11,14247	49,83813	11,88084	10,59357	7,662950	2,776590	6,105457
	7	10,98763	49,18808	11,69671	11,84779	7,552102	2,724881	6,002806
	8	11,22118	48,29366	11,48511	12,25720	7,876494	2,858517	6,007840
	9	11,37484	47,79361	11,38124	12,41400	8,076910	2,999191	5,960219
	10	11,45774	47,64570	11,36318	12,47938	8,087742	3,008991	5,957262
	Period	PCI	FR	MR	SC2	SC3	G	PG
MR	1	0,311918	45,60396	54,08412	0,000000	0,000000	0,000000	0,000000
	2	3,25364	36,93274	46,30800	3,071939	10,29901	0,100577	0,034099
	3	2,691266	30,80788	40,33505	11,17243	9,982137	1,619256	3,391983
	4	2,679081	28,87421	37,60638	14,16369	11,46535	1,652107	3,559177
	5	2,491609	26,25664	34,24679	20,15560	10,63048	2,222910	3,995975
	6	2,490075	25,93608	33,21139	21,92272	10,30877	2,158965	3,972000
	7	2,834331	25,19103	31,95499	22,80752	10,89821	2,256431	4,057485
	8	3,258510	24,84503	31,44559	22,81019	11,20910	2,432527	3,999055
	9	3,502260	24,75471	31,29208	22,77170	11,23305	2,443548	4,002655
	10	3,549159	24,73096	31,24763	22,78292	11,23008	2,457332	4,001918
	Period	PCI	FR	MR	SC2	SC3	G	PG
PCI	1	100,0000	0,000000	0,000000	0,000000	0,000000	0,000000	0,000000
	2	48,45043	2,254807	0,447244	0,369207	20,66707	26,67108	1,140168
	3	44,14811	4,702253	1,697889	1,075962	21,46426	24,80724	2,104283
	4	42,56406	4,798940	2,652671	1,035173	22,84831	23,99544	2,105402
	5	41,26284	4,873330	3,391700	1,197892	23,65832	23,31913	2,296779
	6	40,43190	4,766497	3,319527	1,200158	25,16016	22,84706	2,274692
	7	39,80038	4,692679	3,340661	2,309875	24,97739	22,62578	2,253231
	8	39,20589	4,684126	3,291989	3,405634	24,88955	22,26751	2,255290
	9	38,71875	4,666758	3,291296	4,389369	24,53105	22,01191	2,390863
	10	38,40288	4,731575	3,283166	5,031744	24,31513	21,84260	2,392912
	Period	PCI	FR	MR	SC2	SC3	G	PG
PG	1	0,494800	8,370658	4,799842	1,722294	0,187431	12,65914	71,76583
	2	8,109033	12,26932	4,354042	5,252438	2,925738	11,63214	55,45728
	3	8,486033	11,20716	5,462217	6,113659	2,781500	13,34904	52,60039
	4	8,976607	11,52385	5,257613	5,814285	3,183981	15,12689	50,11677
	5	8,801600	11,29304	5,163299	5,803762	5,077075	14,81390	49,04733
	6	8,872829	11,05655	5,751509	6,115224	5,401503	14,60965	48,19274
	7	8,831715	11,05867	5,777933	6,481720	5,376950	14,53972	47,93329
	8	8,878801	11,06872	5,774599	6,494212	5,371525	14,52631	47,88583
	9	8,903967	11,01048	5,743197	6,590863	5,571237	14,55555	47,62471
	10	8,937635	11,01102	5,761127	6,613985	5,570866	14,54932	47,55605

	Period	PCI	FR	MR	SC2	SC3	G	PG
SC2	1	3,259257	0,239782	0,375218	96,12574	0,00000	0,00000	0,00000
	2	3,053172	0,807269	0,920466	93,32963	0,255236	0,003143	1,631086
	3	3,297405	1,245154	0,754586	90,97497	0,327943	0,161144	3,238794
	4	3,708095	2,111574	1,043617	88,94383	0,956060	0,286703	2,950123
	5	4,862275	2,464303	1,305663	86,38127	1,490774	0,470453	3,025262
	6	5,397217	2,605359	1,338980	84,93926	1,841744	0,762667	3,114771
	7	5,614296	2,759517	1,479567	84,44208	1,829981	0,775807	3,098751
	8	5,698255	2,817389	1,500722	84,27444	1,815772	0,775172	3,118248
	9	5,725630	2,847624	1,538612	84,18810	1,814356	0,775603	3,110077
	10	5,736744	2,857696	1,545833	84,13893	1,842103	0,773132	3,105558
	Period	**PCI**	**FR**	**MR**	**SC2**	**SC3**	**G**	**PG**
SC3	1	4,593052	2,405365	0,146636	10,13319	82,72176	0,00000	0,00000
	2	5,032077	3,065503	0,130306	9,844775	80,30571	1,552914	0,068720
	3	4,305732	3,236068	0,373188	10,45052	79,08696	2,380688	0,166850
	4	4,195269	3,153529	0,448194	17,61296	71,60595	2,176174	0,807925
	5	4,353416	3,395404	0,551524	23,00290	64,76301	2,612258	1,321486
	6	5,249176	3,922243	0,644182	26,20757	59,45728	2,899939	1,619610
	7	6,019319	4,264094	0,616636	27,42515	56,50016	3,261032	1,913606
	8	6,591436	4,544920	0,754228	28,08561	54,58463	3,456879	1,982300
	9	6,918367	4,704509	0,812696	28,31707	53,72190	3,484194	2,041257
	10	7,044680	4,775678	0,856110	28,52814	53,24495	3,493392	2,057057
	Period	**PCI**	**FR**	**MR**	**SC2**	**SC3**	**G**	**PG**
G	1	57,97542	0,040554	2,547494	1,112309	0,357916	37,9663	0,00000
	2	29,20602	1,318289	2,964662	8,413718	22,79929	35,28774	0,010286
	3	21,48896	1,772458	7,174022	16,94186	26,77293	25,54476	0,305009
	4	20,33039	1,991945	9,955433	15,82580	28,70801	22,89547	0,292949
	5	19,83148	1,927678	9,885482	15,28824	30,31929	21,99392	0,753918
	6	19,15124	1,969066	9,859680	14,68063	32,11608	21,44737	0,775925
	7	18,82795	1,935913	9,877476	15,76470	31,56005	21,25573	0,778177
	8	18,74646	1,997487	9,806911	16,28116	31,27862	21,09040	0,798951
	9	18,62846	2,005492	9,733011	16,54468	31,17562	20,94112	0,971625
	10	18,60262	2,091615	9,708425	16,59311	31,17247	20,85950	0,972265

the Galor-Weil (2000) model is demonstrated more clearly.

According to the variance decomposition test results, 80% of the change in fertility in the short run is explained by itself and 20% by growth in per capita income. These results are consistent with the Malthusian trap. According to Malthus (1798), the increase in welfare increases fertility in societies that have not achieved educational and technological breakthroughs. Initially, a quarter of the South Korean fertility rate could be explained by the increase in the welfare of individuals. However, in the long run, the explanation power of the change in fertility shifted towards secondary and tertiary education and newborn mortality. According to Galor and Weil (2000), parents choose between the quality and quantity of their children. In South Korea, which is trying to escape from the Malthusian trap, parents changing their preferences from quantity to quality over time increases the explanation power of education on fertility. Moreover, the decline in newborn mortality rates reduces fertility because the decline in newborn mortality rates also reduces the loss of quantity, erasing the need to increase fertility to maintain quantity. This view is consistent with the theory of Galor and Weil (2000).

While 54% of the short-run change in the newborn mortality rate is explained by itself, 45% is explained by fertility. In the long run, the explanation power of the newborn mortality rate and fertility shifts towards secondary and tertiary education. Secondary education, in particular, has an explanation power of one-quarter over the newborn mortality rate. In the Malthusian trap, a circle exists between fertility and newborn mortality. Fertility increases due to high newborn mortality rates. The newborn mortality rate increases as fertility increases. Because the health sector, which develops with social awareness and technology, is not at an adequate level, the cycle between fertility and newborn mortality rates continues. Therefore, the explanation power of the fertility rate on newborn mortality rate in the short run in South Korea is consistent with the Malthusian trap. In the following period, the explanation power of education levels on newborn mortality rate is consistent with the theory of Galor-Weil (2000).

In the short run, changes in growth in per capita income are completely explained by itself. However, from the second period onwards, tertiary education and technology have an explanation power of one-fourth of the growth in per capita income. The increase in technology has a positive effect on output and leads to an increase in people's income. The increase in secondary and tertiary education increases human capital by increasing the amount of qualified output, which in turn increases growth in per capita income. Therefore, the effect of advanced education level and technology on growth in per capita income in South Korea is consistent with the theory of Galor-Weil (2000).

In the short run, 71% of the population growth rate is explained by itself, while 12% is explained by technology, and 8% by fertility. In the long run, while the self-explanation power of the population growth rate falls below 50%, the explanation power of fertility increases to 11%, the explanation power of technology increases to 14%, and the explanation power of growth in per capita income increases from zero to 8%.

While almost all of the change in secondary education in the short run is explained by itself, this rate drops to 84% in the long run. Other variables explain the difference to a very small extent. According to the theory, the initial change in the level of education is considered exogenous. Therefore, the variance decomposition results for secondary education in South Korea are consistent with the theory of Galor-Weil (2000).

In the short run, 82% of the change in tertiary education is explained by itself, while this rate drops to 53% in the long run. The explanation power of secondary-level education increases from 10% to 28%. Historically, tertiary education in South Korea has been preferred by a very limited group of people who initially had secondary education. Therefore, secondary education has no explanatory power over tertiary education. However, the increase in the importance attached to education with the policies towards education has significantly increased the population with secondary education and has had a significant impact on tertiary education in the following periods.

In the short run, 37% of change in technology is explained by itself, while about 57% is explained by growth in per capita income. In the long run, the explanatory power of technology itself decreases to 20%. At the same time, the power of growth in per capita income to explain technology drops to 18% in the long run. In the tenth period, the explanatory power of tertiary education increases up to 31%. The explanatory power of education at the secondary education level increases to 8% in the second period and 16% in the tenth period. Thus, as the Galor-Weil (2000) theory suggests, technological progress, which is initially slow and insufficient, is triggered by the educated population. The education level of the population should also increase to adapt to the accelerating technological progress and realize this progress at a sustainable level. As the analysis shows, while technology in South Korea is initially explained by growth in per capita income, in the long run, the locomotive role is assumed by tertiary education.

According to the variance decomposition test results, the Galor-Weil (2000) model is valid for South Korea. According to the results, technological development is achieved through education. However, the variance decomposition test only provides the option to test the validity of the Galor-Weil (2000) model for South Korea, but it does not provide the possibility to observe the impact of secondary and tertiary education on technology in more detail. It does not provide a clear answer to the question, "Why is tertiary education important for technological development?". ARDL bounds test was applied to overcome these deficiencies. The ARDL bounds testing approach was chosen to reveal the determinants of technology within the framework Galor-Weil model because it can be used without depending on the degree of stationarity of the series, prevents correlation by providing appropriate lag selection, reduces the endogeneity problem, and provides a better understanding of the long-run coefficient (Menegaki, 2019). The level values of the series were used in the ARDL bounds test analysis. In this analysis, factors that indirectly affect technology, such as mortality, fertility, and population growth, are not included. Factors that directly affect technology, including secondary education, tertiary education, and growth in per capita income, are included. With this analysis, the impact of the difference between education levels on technology is examined in more detail.

The specification equation used in this model is as follows:

$$\Delta G_t = \beta_0 + \beta_1 \Delta G_{t-i} + \beta_2 \Delta PCI_{t-i} + \beta_3 \Delta SC2_{t-i} + \beta_4 \Delta SC3_{t-i} + \varepsilon_t.$$

In this equation, β_0 is the constant term. β_1 is the coefficient of the dependent variable and shows the effect of lagged values on the current period. β_2, β_3, and β_4 are the coefficients of lagged values of *PCI*, *SC*2, and *SC*3 series, respectively, and show the effect of past changes in variables on G_t, ε_t is the error term.

The diagnostic test results in Table 6 show the absence of an autocorrelation problem in the model according to the Breusch Godfrey LM test. According to the White and Breusch-Pagan-Godfrey tests, changing variance is not an issue, and according to the Ramsey RESET test, functional form is not a problem. Finally, according to the Jarque-Bera test results, the model is normally distributed at a 5% significance level. The F statistic (47.98) is greater than the Pesaran *et al.*(2001) and Narayan (2005) table critical values, and the t-statistic (-5.35) is greater than the Pesaran *et al.* (2001) table critical values in absolute value. These results indicate the existence of a long-run equilibrium relationship between the variables used in the ARDL model. CUSUM and CUSUM of squares structural break tests were applied to test the

Table 6
ARDL Bounds Test Results

Variable	Coefficient	Std. Error	t-Statistic
sc2	-0,006601***	0.001726	-3.824667
sc3	0,224542***	0.043031	5.218214
pc1	0,019354***	0.005442	3.556552
	Diagnostic Test Results		
Breusch Godfrey Otokor. LM:	0,50 [0,60]		
Variable variance (Harvey):	1,56 [0,17]		
Variable variance (Breusch-Pagan-Godfrey):	1,61[0,15]		
Ramsey RESET:	0,00 [0,96]		
Normal Distribution (JB):	4,30 [0,11]		
ECT	-0,21***		
F- Statistic:	4978,91 [0,00]		
R2 :	0,99		
Cointegration	√		
Cusum	Stable		
Cusum of Square	Stable		

structural breaks in the years subject to the study and the reliability of the findings. According to the test results, the test statistics are within the 5 percent confidence interval. Therefore, structural change could be observed in the estimated coefficients in the base years.

According to Table 5, all variables in the model are meaningful at the 10%, 5%, and 1% levels. The real effects of growth in per capita income, secondary, and tertiary education on technology are calculated using ARDL estimation results. In South Korea, a 1% increase in growth in per capita income growth will cause a 0.01% increase in technology, while a 1% increase in secondary education will cause a -0.006% effect on technology. However, a 1% increase in tertiary education will cause a significant increase of 0.21% in technology.

According to the ARDL bounds test findings, the growth in per capita income in South Korea is insufficient to explain technology in the long run. Although it does not have a significant impact on South Korea, not improving the education level of the labor force and remaining at the level of secondary education also have a negative impact on technological development in the long run. This situation shows the erosion effect mentioned by Galor-Weil (2000). If the population does not increase its level of education, it cannot adapt to the developing technology and thus remains outside the production process. The exclusion of the labor force from the production process not only leads to the inability to use existing technology but also to the inability to advance technology.

In contrast, increasing the education level of the workforce and reaching tertiary education levels will have a significant positive impact on technology. Thus, the effect of different levels of education on technology, which was highlighted by the variance decomposition test, was detailed through the ARDL bounds test. The importance of education levels in the Galor-Weil(2000) model was also revealed.

V. CONCLUSION

Galor-Weil (2000) argues that escape from the Malthusian trap is possible through technological progress accelerated by an educated population. In this study, the Galor-Weil(2000) model is analyzed with the case of South Korea, a small Asian country that missed the industrial revolution in the mid-20th century, was dependent on foreign trade, and could not escape the Malthusian trap. Our review indicates this study is the first empirical study to analyze South Korea within the framework of the Galor-Weil theory. Immediately after South Korea gained independence in 1945, the government tried to close the gap in industrialization by implementing state policies for schooling. These policies provided a demographic transformation and the formation of human capital over time. In the process, it has achieved rapid progress and a high acceleration in terms of technological progress. South Korea's escape from the Malthusian trap by achieving this transformation is explained based on the Galor-Weil model using education, technology, and fertility data of the period when technological progress gained momentum.

According to the results of the VAR analysis, secondary and tertiary education is the Granger causality of technology, mortality rate, and growth in per capita income between 1974–2021. Moreover, in the long run, secondary and tertiary education has 52% explanation power on technology, 29% on income per capita, and 34% on mortality rate. Technology and growth in per capita income are Granger causality of each other. While the explanation power of growth in per capita income for technology is above 57% in the short run, this rate decreases to about 19% in the long run. While the explanatory power of technology for income per capita is zero in the short run, it rises above 21% in the long run. Hence, Granger causality between education levels and fertility does not exist. However, in the long run, secondary and tertiary education has an explanatory power of one-quarter on fertility. In addition, the explanation power of tertiary education for technology and growth in per capita income is higher than that of secondary education. The explanation power of secondary education for mortality is higher than that of tertiary education. The results of the analysis strengthen the consistency between the Galor-Weil (2000) theory and the South Korean miracle.

According to the results of the analysis, South Korea has all the characteristics of economies that have escaped from the Malthusian trap. In addition, technological development through tertiary education continues to increase in this country. Therefore, as a recommendation to countries that have not escaped the Malthusian trap, a categorical evaluation of education can be a starting point for escaping the trap. Studies in the literature that include the Galor-Weil (2000) theory are generally divided into two groups. The first group analyzed countries that escaped the Malthusian trap during the industrial revolution (Alter and Clark, 2010; Crafts and Mills, 2007; Curran and Fröling, 2010; Diebolt and Perrin, 2013; Elgin 2010; Greenwood and Seshadri, 2002; Hansen and Prescott, 2002; Kimura and Yasui, 2010; Kögel, 2001; Dalgaard and Strulik, 2013; Madsen and Strulik, 2023; Perrin, 2011; Steinmann *et al.*,1997; Holger and Jacob, 2007; and Sun and Wei, 2022). The second group analyzed the period before the industrial revolution (Kögel, 2001; Lagerlöf , 2005; Madsen *et al.*, 2019; and Voigtländer and Voth, 2006). The grouping highlights an important gap in the literature in terms of the validity of the model for countries other than developed Western countries because, generally, countries that have not escaped from this trap and missed the Industrial Revolution are in a period dominated by industrialized countries.

Therefore, analyzing the model for these country groups contributes to academic and policy development processes. Today, the inability of societies to achieve demographic transformation on their own requires the right government interventions to avoid the Malthusian trap. Governments can achieve social transformation through goal-oriented education policies because if target-oriented education policies are implemented successfully, a conscious society changes its preference from quality to quantity in family planning. This process is the first stage of escape from the trap. An increasingly educated population can accelerate technological progress up to a limit. To avoid this trap completely and maintain technological progress, support for education should continue, and the population should be stimulated to pursue tertiary education. The education policies to be implemented initially raise the education of the population at the secondary level, thereby raising social awareness and taking the first step towards demographic transformation. However, if the population is not educated at the tertiary level for the sustainability of technological progress, human capital cannot adapt to technology. In this case, the process of escape from the trap is incomplete. At this stage, the increase in the population educated at the tertiary level guides technological progress and contributes to the escape from the Malthusian trap. As a result, to escape from the Malthusian trap, the social structure needs to change from quantity to quality, and the level of quality should be increased. In this way, countries trying to escape from the trap can achieve a higher level of success.

(Submitted Jun 12, 2024; Revised Oct 16, 2024; Accepted Oct 20, 2024)

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