

Taghizadeh-Hesary, Farhad et al.

**Working Paper**

## Economic burden of neurological disorders in an aging society (Japan): A panel data analysis

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## **ADB Working Paper Series**

### **ECONOMIC BURDEN OF NEUROLOGICAL DISORDERS IN AN AGING SOCIETY (JAPAN): A PANEL DATA ANALYSIS**

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**Abstract**

Japan's aging population poses a variety of problems, one of which is the increase in neurological disorders. In this study, we propose a framework quantifying the decline in gross domestic product (GDP) resulting from the reduction of labor from two neurological disorders, Alzheimer's disease and strokes. Using panel data from Japanese prefectures between 2001 and 2012, this analysis first estimates the hours of labor lost due to the prevalence of or the informal care associated with the two diseases. This measure gives us an approximation of the total loss of GDP per prefecture due to these neurological disorders. Our findings show that the loss has been decreasing, but remains higher than that estimated using accounting methods. This evolution might be explained by higher values for capital and total factor productivity. In addition, it appears that the GDP of urban prefectures and prefectures relying heavily on tourism are less affected by the labor shortage. The study confirms the importance of investments in research and development (R&D) and capital stock to soften the effects of labor shortages. Nevertheless, given the aging trend in Japan and many other G20 economies, increasing R&D and private capital stock may not prove sustainable in the future.

**Keywords:** neurological disorders, Alzheimer's disease, stroke, aging population, Japan

**JEL Classification:** I18, J14, E13

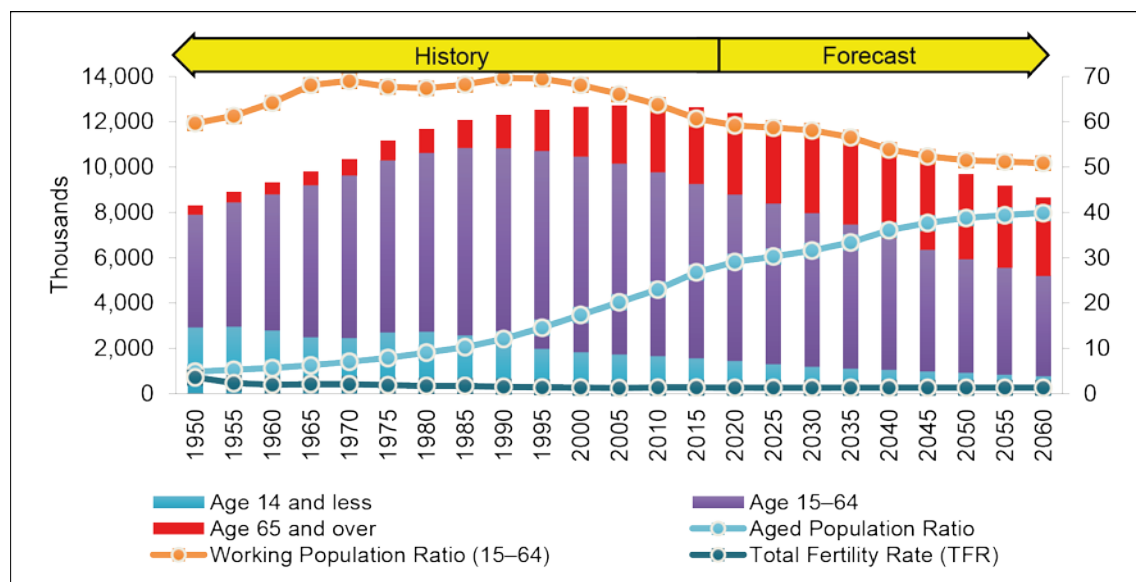
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# 1. INTRODUCTION

Japan is one of the most aged societies in the world (Kondo 2016; Miyabayashi et al. 2019). As illustrated by Figure 1, its working population ratio has been decreasing sharply over the years (OECD 2019), falling from almost 70% of the total population in the 1980s to 60% in the 2010s. In addition, the country's low fertility rate (Allen 2018) and early retirement age (Alfredsson and Winther 2019) have led to an increasingly aged population ratio (Turner 2009). From an economic perspective, an aging society translates into higher social welfare costs (Takasaki, Kawachi, and Brunner 2012; Hsu and Yamada 2019) and decreased domestic consumption (Yoshino and Taghizadeh-Hesary 2017). Furthermore, the country has witnessed increases in certain types of neurological diseases, including Alzheimer's disease (AD) (Sekita et al. 2010; Dodge et al. 2012) and strokes (Takashima, Arima, and Kita 2017; Venketasubramanian et al. 2017). In 2017, AD and strokes represented the leading causes of death in the country (Nomura et al. 2015), representing 14.5% and 10.2% of deaths, respectively (IHME 2019). Given the demographic trend in Japan (Nomura et al. 2015), it is likely that AD cases and strokes will keep increasing in the upcoming years, affecting the national economy as a result.

**Figure 1: Demographics of Japan**



Source: Government of Japan, Ministry of Internal Affairs and Communications (2012).

A careful review of the relevant literature has proved that most studies related to the economic burden of neurological diseases have used an accounting approach to determine costs. Using baseline cost (Dodel et al. 2015), socioeconomic cost per patient (Jia et al. 2018a), and cost of illness (Wimo et al. 2017), existing studies have carefully accounted for the costs of AD throughout the years. In addition, some authors have considered the costs of informal care (Colucci et al. 2014), usually provided by relatives but often overlooked for AD (Gervès, Bellanger, and Ankri 2013; Dodel et al. 2015; Wimo et al. 2017; Jia et al. 2018a; Sado et al. 2018). Studies accounting for the overall costs of strokes have similarly represented the majority of published work on the topic. Again, the methodologies have differed across studies. For instance, direct costs (namely cost of diagnosis, cost per inpatient and per outpatient) were used by Maredza and Chola

(2016), while Matsumoto et al. (2017) used the cost of illness method. The closest approach to this study was undertaken by Keogh-Brown et al. (2017), as they used data on prevalence, morbidity, and mortality to simulate the future costs arising from AD in the People's Republic of China (Jia et al. 2018b), and predicted the effects on gross domestic product (GDP) and labor loss using a computable general equilibrium (CGE) framework. To the best of our knowledge, no study has attempted to compute the loss of GDP resulting from AD or strokes in Japan.

To fill this gap in the literature, the present study attempts to assess the economic burden these two diseases on the labor force and regional GDP. Using time-series panel data of the 47 prefectures between 2001 and 2012, this research first quantifies labor loss due to the selected neurological disease, and then estimates the resulting loss in regional GDP. This research focuses on just two types of neurological diseases, AD and strokes (Amin et al. 2019), as they represent the leading causes of death in the country. The paper is structured as follows: Section 2 presents the theoretical framework, Section 3 introduces the results of the empirical analysis, and Section 4 concludes.

## 2. THEORETICAL MODEL

In order to quantify the decrease in production due to the loss of labor, we first define a production function, establishing a relationship between output and labor. Equation (1) is a Cobb-Douglas-type of production function (Douglas 1976), and provides that total output  $Y$  is a function of three parameters: capital  $K$ , labor supply  $L_S$ , and total factor productivity (TFP)  $A$ .

$$\ln Y = \alpha \ln A + \beta \ln K + \gamma \ln L_S \quad (1)$$

The next step in our analysis is to define  $L_T$ , a total measure of the labor force that would not be affected by AD or strokes.  $L_T$  is given by Equation (2) as the sum of the labor supply  $L_S$ , the number of cases or prevalence  $N$ , and informal care given by relatives  $L^N$ .

$$L_T = L_S + N + L^N \quad (2)$$

To be precise, we express  $L_T$  as hours worked, given that  $L^N$  is traditionally measured in terms of the number of hours of informal care. To this end, we introduce  $d_i$ , a discount factor measuring the yearly hours of informal care needed per patient. The value of the discount factor is retrieved from the literature on AD (Gervès, Bellanger, and Ankri 2013) and strokes (van den Berg et al. 2006; Riewpaiboon et al. 2009; Government of Japan, Ministry of Internal Affairs and Communications 2012). In addition,  $N$  is limited to prevalence in the working population (between ages 15 and 64).

$$L_T = (L_S * h) + (N_{Al;15-64} + N_{St;15-64}) * h + (d_{Al} * N_{Alzh;total} + d_{St} * N_{St;total}) \quad (3)$$

Where  $d_i$  is the discount factor of disease  $i$ ,  $N_{i;j}$  is the number of cases of disease  $i$  in the population  $j$ , and  $h$  is the average hours worked per person and per year.

$$\ln Y_t = \alpha \ln A + \beta \ln K + \gamma \ln L_T \quad (4)$$

Finally, we plug the estimated value of  $L_T$  in Equation (1), using the estimated parameters for coefficients  $\alpha$ ,  $\beta$  and  $\gamma$  in order to obtain the loss in output due to the shortage of labor.

### 3. EMPIRICAL ANALYSIS

In order to proceed with the analysis, data for parameters  $Y$ ,  $A$ ,  $K$ , and  $L_S$  are gathered first. This study uses yearly statistics from the 47 prefectures of Japan between 2001 and 2012. Prefectural GDP is retrieved from the Cabinet Office's Official Statistics, and used as  $Y$ . Real capital stock from the private sector is used as a measure for  $K$ , using data from the Research Institute of Economy, Trade and Industry (RIETI). Finally, total expenditures for technological and scientific research and total hours worked per year are used for  $A$  and  $L_S$ , respectively. Both are retrieved from the Official Statistics of Japan. Data on prevalence for  $L_T$  are retrieved from the Global Health Data Exchange (GHDx) database. Several preliminary tests for the suitability of the data of equation (1) were then conducted, and are detailed in the Appendix. The tests' results show that all variables are stationary in first differences, and are cointegrated. For this reason, the authors use a fully modified ordinary least squares (FM-OLS) estimation method to obtain coefficients  $\alpha$ ,  $\beta$  and  $\gamma$  from Equation (1). The results of the regression are presented in Table 1.

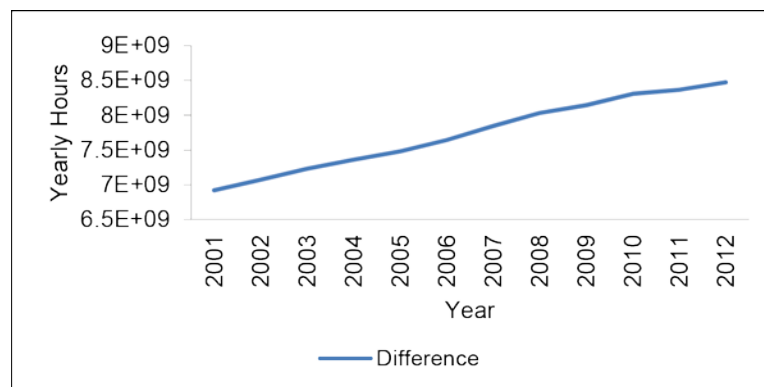
**Table 1: Regression Results using Fully Modified Ordinary Least Squares**

Variable	Coefficient	Standard Error	T-statistic
$\ln A$	0.01*	0.00	3.25
$\ln K$	0.51*	0.03	14.81
$\ln L_S$	0.25*	0.02	12.82

Dependent Variable:  $\ln Y$ . R-squared: 0.99. Adjusted R-squared: 0.99.

The results of the regression show that all parameters are statistically significant at the 5% level, hence giving reliable coefficients for  $\alpha$ ,  $\beta$ , and  $\gamma$ . The next step in the analysis is to estimate  $L_T$ . By definition, the difference between  $L_T$  and  $L_S$  should remain positive. However, given the growth in cases of AD and strokes over the years, the difference between  $L_T$  and  $L_S$  has been constantly increasing over the years, as illustrated by Figure 2.

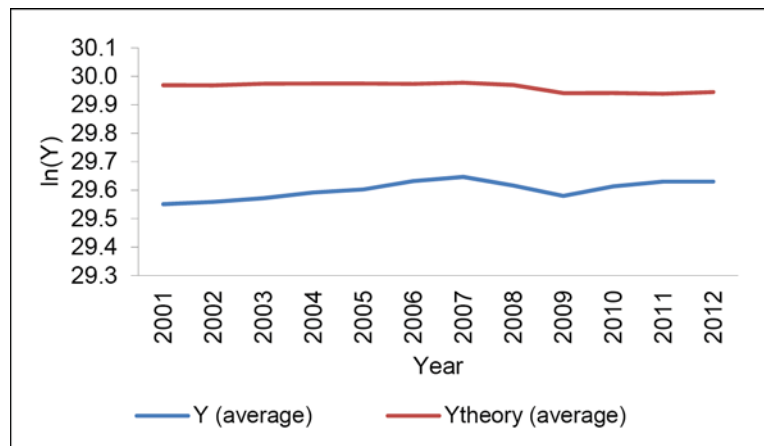
**Figure 2: Difference between  $L_T$  and  $L_S$**



Source: Authors' compilation.

Using the estimates obtained for  $\alpha$ ,  $\beta$ , and  $\gamma$ ,  $L_T$  is plugged into Equation (1) to obtain  $Y_T$ , a theoretical estimation of what GDP should be without the loss of labor due to AD and strokes. The difference between  $Y$  and  $Y_T$  is illustrated in Figure 3, and represents the average estimates from all prefectures.



**Figure 3: Difference between Average  $Y$  and  $Y_T$** 

Source: Authors' compilation.

As predicted by the model, computed GDP using  $L_T$  is higher than observed GDP. The difference between the two, which was greatest in 2001, is 0.42%. However, it is interesting to note that despite a steady increase in the shortage of labor over the years, the gap between actual and predicted GDP is shrinking, being 0.31% in 2012. This evolution could be explained by higher values for  $K$  (capital) and  $A$  (total factor productivity). To compensate for the shortage of labor, prefectures across Japan have been investing more in technological and scientific research, and the private sector has increased its capital stock.

**Table 2: Average Estimated Loss of GDP per Prefecture**

Rank	Prefecture	Estimated Loss	Rank	Prefecture	Estimated Loss	Rank	Prefecture	Estimated Loss
1	Okinawa	-0.52	17	Ehime	-0.38	33	Okayama	-0.33
2	Aomori	-0.51	18	Gunma	-0.38	34	Tochigi	-0.32
3	Niigata	-0.50	19	Mie	-0.38	35	Fukui	-0.31
4	Hokkaido	-0.49	20	Fukuoka	-0.37	36	Ishikawa	-0.30
5	Saitama	-0.45	21	Shizuoka	-0.37	37	Yamaguchi	-0.30
6	Ibaraki	-0.45	22	Kagoshima	-0.37	38	Toyama	-0.30
7	Nagasaki	-0.43	23	Kanagawa	-0.37	39	Osaka	-0.29
8	Nagano	-0.43	24	Chiba	-0.36	40	Yamanashi	-0.29
9	Iwate	-0.43	25	Akita	-0.36	41	Wakayama	-0.29
10	Saga	-0.43	26	Oita	-0.36	42	Tokushima	-0.28
11	Shimane	-0.42	27	Kochi	-0.35	43	Nara	-0.26
12	Kumamoto	-0.42	28	Gifu	-0.35	44	Kagawa	-0.25
13	Yamagata	-0.42	29	Aichi	-0.35	45	Shiga	-0.22
14	Hyogo	-0.42	30	Miyagi	-0.35	46	Kyoto	-0.22
15	Miyazaki	-0.40	31	Tottori	-0.35	47	Tokyo	-0.08
16	Fukushima	-0.39	32	Hiroshima	-0.34			

Source: Authors' compilation.

Finally, Table 2 displays the difference between  $Y$  and  $Y_T$  per prefecture. Urban prefectures such as Tokyo and Osaka have tended to suffer less from a loss of GDP than rural counterparts, such as Aomori, Niigata, and Hokkaido. In addition, prefectures that rely heavily on tourism such as Kyoto, Nara and, to a lesser extent, Kagawa, have exhibited smaller losses due to the shortage of labor as a consequence of AD and

strokes. Furthermore, the GDP of regions such as Hokkaido, Tohoku, and Kyushu have been particularly affected by AD and strokes, while regions such as Kansai, Chugoku, and Shikoku have suffered fewer losses, with some prefectures representing exceptions in both cases.

## **4. CONCLUSION**

This research has explored the burden of two neurological diseases (AD and strokes) on the Japanese economy. Whereas most previous studies on the topic have tended to focus on accounting the costs associated with these diseases, this investigation has explored the loss of GDP as a consequence of the reduction of the labor force due to prevalence and informal care. Our study has confirmed that economic costs as a result of labor loss are greater than accounting costs. In addition, the empirical analysis has confirmed that the loss of labor due to AD and strokes has been increasing over the past decade. However, thanks to increased investments in R&D and higher private capital stock, the loss of GDP has declined only slightly during the period of study. Nevertheless, given the aging trend of Japan's population and many other G20 economies, increasing R&D and private capital stock may not prove sustainable in the future. Appropriate nursing expenditure and supportive plans for outpatients might provide ways to reduce the loss of labor by decreasing informal care and lightening the burden placed on relatives. As a result, labor losses would be reduced and official outpatient care could increase GDP, as informal care is currently unaccounted for. As has been demonstrated, AD and strokes present major challenges to the Japanese economy. The economic burden posed by the two diseases thus illustrates the necessity of utilizing early interventions preventatively and therapeutically in order to alleviate the enormous costs of these ailments on the economy as a whole.

## REFERENCES

- Alfredsson, J., and A. Winther. 2019. *Population Ageing and Average Retirement Age: A Cross-Sectional Analysis on OECD Countries* (Bachelor's dissertation). Jönköping University.
- Allen, T. 2018. Declining Fertility in a Rapidly Aging Japan. *Colloquium: The Political Science Journal of Boston College* 2(2).
- Amin, R., T. Kitazawa, Y. Hatakeyama, K. Matsumoto, S. Fujita, K. Seto, et al. 2019. Trends in Hospital Standardized Mortality Ratios for Stroke in Japan between 2012 and 2016: A Retrospective Observational Study. *International Journal for Quality in Health Care* mzz091.
- Colucci, L., M. Bosco, A. M. Fasanaro, G. L. Gaeta, G. Ricci, and F. Amenta. 2014. Alzheimer's Disease Costs: What We Know and What We Should Take into Account. *Journal of Alzheimer's Disease* 42(4): 1311–1124.
- Dodel, R., M. Belger, C. Reed, A. Wimo, R. W. Jones, M. Happich, J. M. Argimon, G. Bruno, B. Vellas, and J. M. Haro. 2015. Determinants of Societal Costs in Alzheimer's Disease: GERAS Study Baseline Results. *Alzheimer's & Dementia: The Journal of the Alzheimer's Association* 11(8): 933–945.
- Dodge, H. H., T. J. Buracchio, G. G. Fisher, Y. Kiyohara, K. Meguro, Y. Tanizaki, and J. A. Kaye. 2012. Trends in the Prevalence of Dementia in Japan. *International Journal of Alzheimer's Disease* 2012: 956354.
- Douglas, P. H. 1976. The Cobb-Douglas Production Function Once Again: Its History, Its Testing, and Some New Empirical Values. *Journal of Political Economy* 84(5): 903–915.
- Gervès, C., M. M. Bellanger, and J. Ankri. 2013. Economic Analysis of the Intangible Impacts of Informal Care for People with Alzheimer's Disease and Other Mental Disorders. *Value in Health: The Journal of the International Society for Pharmacoeconomics and Outcomes Research* 16(5): 745–754.
- Government of Japan, Ministry of Internal Affairs and Communications. 2012. *Basic Survey on Employment Structure*. Tokyo: Government of Japan.
- Hsu, M., and T. Yamada. 2019. Population Aging, Health Care, and Fiscal Policy Reform: The Challenges for Japan. *The Scandinavian Journal of Economics* 121(2): 547–577.
- Institute for Health Metrics and Evaluation (IHME). 2019. Japan. <http://www.healthdata.org/japan> (accessed 9 September 2019).
- Jia, J., C. Wei, S. Chen, F. Li, Y. Tang, W. Qin, et al. 2018b. The Cost of Alzheimer's Disease in China and Re-Estimation of Costs Worldwide. *Alzheimer's & Dementia* 14(4): 483–491.
- Jia, L., J. Jia, C. Wei, S. Chen, F. Li, F. Li, D. Li, et al. 2018a. The Cost of Alzheimer's Disease in China and Re-Estimation of Costs Worldwide. *Alzheimer's & Dementia: The Journal of the Alzheimer's Association* 14(4): 483–491.
- Keogh-Brown, M. R., H. T. Jensen, H. M. Arrighi, R. D. Smith. 2016. The Impact of Alzheimer's Disease on the Chinese Economy. *EBioMedicine* 4: 184–190.
- Kondo, K. 2016. Progress in Aging Epidemiology in Japan: The JAGES Project. *Journal of Epidemiology* 26(7): 331–336.

- Maredza, M., and L. Chola. 2016. Economic Burden of Stroke in a Rural South African Setting. *eNeurologicalSci* 3: 26–32.
- Matsumoto, K., Si. Hanaoka, Y. Wu, and T. Hasegawa. 2017. Comprehensive Cost of Illness of Three Major Diseases in Japan. *Journal of Stroke and Cerebrovascular Diseases* 26(9): 1934–1940.
- Miyabayashi, I., M. Washio, T. Yanagimoto, E. Fortin, and S. Yasumura. 2019. Population Aging and Health of Older People in Japan: Introduction of Health Issues and Care System for the Elderly. In *Health Issues and Care System for the Elderly*, edited by M. Washio and C. Kiyohara. Singapore: Springer Singapore.
- Nomura, S., H. Sakamoto, S. Glenn, Y. Tsugawa, S. K. Abe, M. M. Rahman, et al. 2017. Population Health and Regional Variations of Disease Burden in Japan, 1990-2015: A Systematic Subnational Analysis for the Global Burden of Disease Study 2015. *Lancet* 390(10101): 1521–1538.
- Organisation for Economic Co-operation and Development (OECD). 2019. Labour Market Reform in Japan to Cope with a Shrinking and Ageing Population. Report No. 1568. [https://www.oecd-ilibrary.org/economics/labour-market-reform-in-japan-to-cope-with-a-shrinking-and-ageing-population\\_73665992-en](https://www.oecd-ilibrary.org/economics/labour-market-reform-in-japan-to-cope-with-a-shrinking-and-ageing-population_73665992-en). Accessed 2 March 2020.
- Riewpaiboon, A., Riewpaiboon, A., Riewpaiboon, W., Ponsoongnarn, K., and van den Berg, B. 2009. Economic Valuation of Informal Care in Asia: A Case Study of Care for Disabled Stroke Survivors in Thailand. *Social Science and Medicine* 69(4): 648–653.
- Sado, M., A. Ninomiya, R. Shikimoto, B. Ikeda, T. Baba, K. Yoshimura, and M. Mimura. 2018. The Estimated Cost of Dementia in Japan, the Most Aged Society in the World. *PloS One* 13(11): e0206508–e0206508.
- Sekita, A., T. Ninomiya, Y. Tanizaki, Y. Doi, J. Hata, K. Yonemoto, H. Arima, K. Sasaki, M. Iida, T. Iwaki, S. Kanba, and Y. Kiyohara. 2010. Trends in Prevalence of Alzheimer's Disease and Vascular Dementia in a Japanese Community: The Hisayama Study. *Acta Psychiatrica Scandinavica* 122(4): 319–325.
- Takasaki, Y., I. Kawachi, and E. J. Brunner. 2012. Japan's Answer to the Economic Demands of an Ageing Population. *BMJ* 345: e6632–e6632.
- Takashima, N., H. Arima, and Y. Kita. 2017. Incidence, Management and Short-Term Outcome of Stroke in a General Population of 1.4 Million Japanese - Shiga Stroke Registry. *Circulation Journal* 81: 1636–1646.
- Turner, A. 2009. Population Ageing: What Should We Worry about? *Philosophical Transactions of the Royal Society B: Biological Sciences* 364(1532): 3009–3021.
- van den Berg, B., Fiebig, D. and Hall, J. 2006. Economic Valuation of Informal Care: Lessons from the Application of the Opportunity Costs and Proxy Good Methods. *Social Science and Medicine* 62(4): 835–845.
- Venketasubramanian, N., B. W. Yoon, J. Pandian, and J. C. Navarro. 2017. Stroke Epidemiology in South, East, and South-East Asia: A Review. *Journal of Stroke* 19(3): 286–294.
- Wimo, A., M. Guerchet, G.-C. Ali, Y.-T. Wu, A. M. Prina, B. Winblad, L. Jönsson, et al. 2017. The Worldwide Costs of Dementia 2015 and Comparisons with 2010. *Alzheimer's & Dementia: The Journal of the Alzheimer's Association* 13(1): 1–7.

Yoshino, N., and F. Taghizadeh-Hesary. 2017. *Japan's Lost Decade: Lessons for Asian Economies*. Tokyo: ADB Institute Series on Development Economics.

## APPENDIX 1: DESCRIPTIVE STATISTICS

Variable	Description	Unit	Source	Mean	Maximum	Minimum	Standard Deviation
lnY	Prefectural GDP	Yen	Cabinet Office of Japan Official Statistics	29.60	32.25	28.29	0.83
lnA	Total Expenditures for Technological and Scientific Research	Yen	e-Stat, official statistics of Japan	22.46	24.21	20.99	0.51
lnK	Real capital stock of the private sector	Yen	RIETI	30.52	32.55	29.24	0.74
lnLs	Total worked hours per year	Hours	e-Stat, official statistics of Japan	21.24	23.47	20.04	0.75

Source: Authors' compilation.

## APPENDIX 2: UNIT ROOT TESTS

Variable	Fisher ADF	Levin, Lin, and Chu	Philips-Perron Fisher	Stationarity
lnY	143.92*	-9.29*	137.93*	Yes
D(lnY)	225.31*	-16.97*	258.31*	Yes
lnA	94.41	-3.22*	150.42*	Yes
D(lnA)	217.90*	-9.58*	509.73*	Yes
lnK	99.57	-4.53*	107.82	No
D(lnK)	99.94	-2.48*	222.76*	Yes
lnLs	20.52	1.02	25.26	No
D(lnLs)	121.59*	-3.17*	290.40*	Yes

Source: Authors' compilation.

## APPENDIX 3: COINTEGRATION TESTS: PEDRONI RESIDUAL COINTEGRATION TEST

### Alternative Hypothesis: Common Autoregressive (AR) Coefficients (within-dimension)

	Non-Weighted		Weighted	
	Statistic	Probability	Statistic	Probability
Panel v-Statistic	<b>0.06</b>	<b>0.4759</b>	<b>-2.08</b>	<b>0.9816</b>
Panel rho-Statistic	2.09	0.9819	2.24	0.9875
Panel PP-Statistic	-8.32	0.0000	-10.22	0.0000
Panel ADF-Statistic	-8.33	0.0000	-8.73	0.0000

### Alternative Hypothesis: Individual Autoregressive (AR) Coefficients (between-dimension)

	Statistic	Prob.
Group rho-Statistic	5.21	1.0000
Group PP-Statistic	-16.25	0.0000
Group ADF-Statistic	-10.07	0.0000

Null hypothesis: no cointegration.

Trend assumption: no deterministic trend.

Source: Authors' compilation.