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Abstract

A low population density and a large distance from civilization centres present a high degree of isolation to the island's residents. Immigration can reduce the mental and material costs of isolation for the veteran residents, but at the expense of cultural and national cohesion and social harmony; and, in the case of an arid land, also at the expense of the amount and price of water allocated to agriculture. An expected-net-benefit-maximisation model for determining population size and its equilibrium urban-rural composition is developed. It is simulated for various agricultural water prices. The simulation results illustrate the central role of the effect of immigration on the urban unemployment rate in the determination of the island's efficient population size.

(*JEL* O13, O15, O18, O21, O41, O50, P25, P28, R12, R23)

Keywords: Water prices, isolation costs, cohesion costs, environmental costs, employment prospects, population size, immigration, urban-rural composition

1. Introduction

This paper deals with the issue of efficient population size and rural-urban composition of a distant, large arid island. The island's current population is small and, due to a low fertility rate, its natural growth rate is minute. The island's inhabitants bear mental and material costs of isolation—distance and dispersion hinder communication and provision of commodities and services. Immigration is the main way for increasing the island's population density, strengthening the island's international integration and, thereby, moderating the costs of isolation borne by the island's inhabitants. However, immigration reduces the island's levels of cultural and social cohesion. It also affects the island's rural and urban land and water use and, thereby, the island's environment.

Australia is an outstanding example of such an island. It has roughly the land-size of the United States without Alaska. Similar to the United States, it is endowed with attractive natural, social, political and economic amenities. However, the size of the population of Australia is just fifty-five percent of the size of the ethnically diversified population of California—a frontier, largely arid land a hundred and fifty years ago and presently the United States' most populous, progressive and influential state and the world's fifth largest economy—whose land-size is a mere five percent of Australia's.[1] As in the case of California, which had been insulated from the much more inhibited eastern coast of the United States by vast plains and rugged mountain ranges, and as in the late 1940s and during the 1950s and 1960s, a large immigration should have strong implications for Australia's isolation costs, ethnic composition, social cohesion, culture, education, stock of human capital, labour supply, domestic

[1] In 1999, the per capita income in Australia and California were USD 20,860 and USD 22,711, respectively. Australia's land is 7,682,000 squared kilometres, whereas the land-size of California is 404,600 squared kilometres—fifty percent the land-size of New South Wales. In 2004 Australia's population was 20 million whereas California's population was estimated to be 36 million.

technology, domestic markets, industrial structure, environment, international affairs and global role.

Australia is the driest continent—a condition that gives rise to Malthusian-type of sustainability arguments in support of small natural population growth and immigration quotas. Betts (1990), Burnley (1990) and Goldie (2002), to mention a few, argue that Australia's fresh water supply is severely limited and any further population growth is environmentally, socially and economically undesired. In contrast, Barney and Franzi (2002) claim in their report to the Australian Department of Immigration and Multicultural and Indigenous Affairs that science and technology will provide a solution to Australia's current water shortages in the near future and will enable Australia to have a population of fifty million people and be a medium-size country by 2100. A position against population-targeting, small or large, and in favour of market-based immigration policies is expressed by Clarke (2003).

This paper argues that Australia's current water shortages are not necessarily caused by population pressure, but are mainly due to inefficiency in the rural-urban allocation of water stemming from a large household-agricultural price differential and a wasteful system of water rights.[2] Hence, Australia's water problem can be resolved and Australia's population can be allowed to grow considerably, even without scientific and technological improvements in the supply of water, by reducing the household-agricultural water price differential and reforming the water-rights system. Although ninety-seven percent of Australia's human inhabitants are urban dwellers, about seventy percent of Australia's annual portable water is used by the agricultural sector. Incompatible with the notion of comparative advantage, the production of some Australian agricultural goods are directly and indirectly

[2] They are also an outcome of an insufficient investment in developing catchment's areas and purification, transportation and waste-treatment systems.

subsidised and much of the amount produced is exported. Taking into account the large household-agricultural water price differential, water-intensive crops such as cotton and rice might belong to the list of inefficient agricultural activities. Moreover, while some up-stream farmers hoard large quantities of water, much of which evaporates, in order to preserve their water rights, urban dwellers are facing fine-enforced restrictions on the purpose and mode of using water.

A simple calculation reveals that, with the current average Australia household’s water consumption, a forty-three percent reduction in the annual amount of water used by farmers may enable Australia to satisfy the household water needs of forty million people—a slightly larger population than that of California. The diversion of fresh water resources from farmers to the more easily and better coordinated and monitored urban users may improve the overall management of Australia’s scarce water resources and reduce the volume of untreated effluents.

The objective of this paper is to develop a socio-economic model for numerically simulating the possible effects of urban-rural water-price differential on the efficient population size and urban-rural composition of a distant, large, arid island similar to Australia.

The paper is structured as follows. The building blocks of the socio-economic model are presented in section 2 and used to construct the interrelationships among land and water availability, population size, personal isolation, social cohesion, environmental damage, bargaining power and urban and rural dwellers’ expected incomes and costs. The equilibrium urban-rural composition is defined in section 3 and incorporated into an expected net benefit maximisation model that generates the efficient population size. The simulation technique and the model parameter values are described in section 4. The simulation results of the effect of urban-rural water price differentials are presented in section 5 for the case of fixed urban unemployment rate and for the cases where the urban unemployment rate diminishes, or rises, with the size of the island's population as the increase in the demand for urban labour generated by the rising aggregate demand for goods exceeds, or exceeded by, the increase in the urban-labour supply. Section 6 concludes.

2. Land, Water and Population: Constraints, Costs and Incomes

The model's building blocks are as follows.

The island's land fit for tillage and habitation is $\hat{L}$ acres. The island's population is N. The average personal residential area is l acres. Hence, the arable land, L_r, is

$$L_r = \hat{L} - lN \, . \tag{1}$$

The island's annual sustainable volume of water available and suitable directly and indirectly (through agricultural goods) for human consumption is $\hat{W}$ cubic metres. The average annual personal household water-consumption is w cubic metres. Hence, the annual amount of water available for farming, W_r, is

$$W_r = \hat{W} - wN \, . \tag{2}$$

The island's workers are equally competent. They and their dependents are divided into N_r rural dwellers and N_u urban dwellers:

$$N_r + N_u = N \, . \tag{3}$$

The island's faces an infinitely elastic supply of equally competent immigrant workers and their dependents, but its population cannot exceed the island's carrying capacity ($N_{\max}$):

$$N \le N_{\max} = \min\{\frac{\hat{L}}{l}, \frac{\hat{W}}{w}\}. \tag{4}$$

For a large but arid island, such as Australia, the carrying capacity is determined by water availability, $N_{\max} = \frac{\hat{W}}{w}$.

The inhabitants of the island bear mental and material costs of isolation. Fertility rate is low and population growth depends entirely on immigration. Immigrants are culturally and socially different from veteran islanders. Hence, while the costs of isolation decrease with the size of the island's population, the cumulative costs of loss of cultural cohesion and social harmony rise.

In particular, the personal isolation costs gradually decline with the size of the local urban and rural communities from a peak of $\hat{c}_u^I$ for an urban dweller and a peak of $\hat{c}_r^I$ for a rural dweller. That is, the isolation cost for an urban dweller is given by

$$c_u^I = \frac{\hat{c}_u^I}{N_u + d_u N_r} = \frac{\hat{c}_u^I}{d_u N + (1 - d_u) N_u} \tag{5}$$

with $0 < d_u \le 1$ indicating that an increase in the number of farmers might have a smaller moderating effect on an urban dweller's isolation cost than a similar increase in the number of urban dwellers. Similarly, the isolation cost for a farmer is given by

$$c_r^I = \frac{\hat{c}_r^I}{N_r + d_r N_u} = \frac{\hat{c}_r^I}{N - (1 - d_r) N_u} \tag{6}$$

with $0 < d_r \le 1$ indicating that an increase in the number of urban dwellers might have a smaller moderating effect on a rural dweller's isolation cost than a similar increase in the number of members in his own sector.

The loss of cultural and national cohesion and social harmony is given by

$$c_u^S = m_u N^{h_u}, \quad m_u, h_u > 0, \tag{7}$$

for an urban dweller and by

$$c_r^S = m_r N^{h_r}, \; m_r, h_r > 0, \qquad (8)$$

for a rural dweller.

Urban dwellers and rural dwellers might also incur political costs (or benefits) in accordance with their sector's relative bargaining power. These political costs (or benefits) take the form of low (or high) level of public investment in infrastructure—schools, utilities and transportation and communication systems. Assuming that a sector's bargaining power depends upon its population share vis-à-vis its counterpart's population share and recalling equation (3), these political costs (benefits) are expressed as

$$c_u^P = y_u[(N_r - N_u)/N] = 2y_u[0.5 - (N_u/N)], \; y_u \geq 0 \qquad (9)$$

for an urban dweller, and

$$c_r^P = y_r[(N_u - N_r)/N] = 2y_u[0.5 - (N_r/N)], \; y_r \geq 0 \qquad (10)$$

for a rural dweller.

A proportion $0 < g_u < 1$ of the urban population belongs to the urban labour force—urban workers hereafter. Correspondingly, the number of dependents per urban worker is $1/g_u - 1$. Each urban worker has a potential income, y_u (a positive scalar), and a probability of being employed that might depend on the island's population size, $0 < f(N) < 1$. Consequently, his, or her, expected income is $f(N)y_u$. *A priori*, the sign of $f'(N)$ is not clear. It is positive, zero, or negative if the number of new urban jobs created by the increased aggregate demand is larger than, equal to, or smaller than, the increase in the labour-supply generated by an infinitesimal population growth (i.e., intake of new immigrants). Under the assumption that the number of new urban jobs created by the increased aggregate demand is *smaller* than the increase in the labour-supply generated by the island's population growth, the probability of being employed in the urban sector is taken to be given by

$$f(N) = 1 - j\,\frac{N}{N_{\max}},\ 0 < j \le 1. \qquad (11)$$

Under the assumption that the number of new urban jobs generated by the increased aggregate demand is *larger* than the increase in the labour-supply generated by the island's population growth, the probability of being unemployed in the urban sector is taken to be given by

$$f(N) = 1 - \tilde{j}\,\frac{N_{\max}}{N},\ 0 < \tilde{j} \le \frac{N}{N_{\max}}\ . \qquad (12)$$

The arable land and the amount of water unconsumed by households are fully used by the agricultural sector. A proportion $0 < g_r < 1$ of the rural population belongs to the rural labour force and taken to be self-employed farmers. The number of dependents per farmer is therefore $1/g_r - 1$. All the farmers are endowed with equal land and water allotments and use the same technology, which can be represented by a Cobb-Douglas production function. That is, each farm's potential annual output is given by $A_r(L_r/g_rN_r)^a(W_r/g_rN_r)^b$, where $A_r > 0$ and $0 < a, b < 1$ indicate the technological shift parameter and production elasticities with respect to land and water, respectively. Each farmer faces a probability $0 < 1 - q < 1$ of production failure due to natural causes. Every farmer receives an exogenously given price, P, on the composite agricultural good. Consequently, and in recalling equations (1), (2) and (3), each farmer's expected revenue is given by

$$\begin{aligned} y_r &= qPA_r[(\hat{L} - lN)/g_r(N - N_u)]^a[(\hat{W} - wN)/g_r(N - N_u)]^b \\ &= qPA_r(\hat{L} - lN)^a(\hat{W} - wN)^b/[g_r(N - N_u)]^{a+b} \end{aligned}\ . \qquad (13)$$

The island's government sets water and environmental rates and invests the revenues collected in transporting fresh water to consumers, treating and disposing effluents and rehabilitating the island's environment. Having $1/g_u - 1$ dependents, each consuming w cubic metres of water per annum, the annual water-bill for any urban worker is

$$c_u^W = wq_u / g_u \tag{14}$$

where q_u is the full-price—including the cost of supply-system service and the cost of treating and disposing effluents—of a cubic metre of urban water. Having $1/g_r - 1$ dependents and a farm, the annual water-bill for a farmer is

$$c_r^W = [w/g_r + (\hat{W} - wN)/g_r N_r]q_r = [w/g_r + (\hat{W} - wN)/g_r (N - N_u)]q_r \tag{15}$$

where q_r is the full-price of a cubic metre of rural water.

The annual environmental bills for urban workers and farmers are equal to the costs of full rehabilitation of the annual degradation of the land and the atmosphere above it. The cost of rehabilitating the annual environmental degradation caused by an urban worker and his, or her, dependents is proportional to their dwelling area

$$c_u^E = e_u (l / g_u) \tag{16}$$

where e_u is the annual environmental rehabilitation cost per acre of urban land. The cost of rehabilitating the annual environmental degradation caused by a farmer and his, or her, dependents is proportional to the sum of their dwelling and farming areas

$$c_r^E = [l/g_r + (\hat{L} - lN)/g_r N_r]e_r = [l/g_r + (\hat{L} - lN)/g_r (N - N_u)]e_r \tag{17}$$

where e_r is the annual environmental rehabilitation cost per acre of rural land.

In addition, the island's residents pay the government annual rents for having property rights on their dwelling land and the buildings on the land. The property rents collected finance the government's activities, excluding the already considered costs of supplying water, treating and disposing effluents and rehabilitating the island's environment. In response to supply and demand conditions, the annual property rent increases with concentration—the sector's population share. It is given by

$$c_u^L = [t_u(N_u / N)](l / g_u) \tag{18}$$

for an urban worker and

$$c_r^L = [t_r(N_r / N)][l / g_r + (\hat{L} - lN) / g_r N_r] \tag{19}$$

for a farmer, where t_r and t_u are positive scalars representing the upper-bound on the property rent per urban acre (i.e., when $N_u \rightarrow N$) and the upper-bound on the property rent per rural acre (i.e., when $N_r \rightarrow N$), and where l / g_u and $l / g_r + (\hat{L} - lN) / g_r N_r$ indicate the average number of acres occupied by an urban worker and a farmer and their dependents, respectively.

3. Rural-Urban Equilibrium and the Island's Efficient Population Size

In view of the aforementioned assumptions and specifications, the expected net benefit for any of the island's urban workers and his, or her, dependents is defined as

$$\begin{aligned} v_u &= f(N)y_u - (c_u^I + c_u^S + c_u^P) / g_u - c_u^W - c_u^E - c_u^L \\ &= f(N)y_u - \{\frac{\hat{c}_u^I}{d_u N + (1 - d_u)N_u} + m_u N^{h_u} + y_u[1 - 2(N_u / N)] + wq_u + (e_u + t_u \frac{N_u}{N})l\} / g_u \end{aligned} \tag{20}$$

and the expected net benefit for any of the island's farmers and his, or her, dependents is

$$
\begin{aligned}
v_r &= y_r - (c_r^I + c_r^S + c_r^P)/g_r - c_r^W - c_r^E - c_r^L \\
&= qPA_r(\hat{L} - lN)^a (\hat{W} - wN)^b \ /[g_r(N - N_u)]^{a+b} \\
&\quad - \{\frac{\hat{c}_r^I}{N - (1 - d_r)N_u} + m_r N^{h_r} + y_u[1 - 2(N_r / N)]\}/g_r \,. \qquad (21) \\
&\quad - [w/g_r + (\hat{W} - wN)/g_r(N - N_u)]q_r \\
&\quad - [l/g_r + (\hat{L} - lN)/g_r N_r][e_r + t_r(N_r / N)]
\end{aligned}
$$

Consistent with Todaro's (1969) hypothesis,[3] a rural-to-urban net migration reflects an adjustment process that exhausts any arbitrage. Namely, $\dot{N}_u(t) = p[v_u(t) - v_r(t)]$ with $p > 0$ denoting the speed of adjustment. As the analysis is concerned with the island's efficient population and decomposition by sector, the case where the island's inhabitants are allowed to enter and exist each sector without delay at any instance is taken into account (i.e., perfectly open access, $p \to \infty$). Consequently, and recalling the assumption that all workers are equally competent, the island's urban-rural structure is in equilibrium with $v_u(t) = v_r(t)$ at every instance, assuming that the transfer costs are negligible. Recalling equations (20) and (21), the island's equilibrium urban-population, N_u^*, satisfies

$$
\begin{aligned}
& f(N)y_u - \{\frac{\hat{c}_u^I}{d_u N + (1 - d_u)N_u^*} + m_u N^{h_u} + y_u[1 - 2(N_u^* / N)] + wq_u + (e_u + t_u \frac{N_u^*}{N})l\}/g_u \\
&= qPA_r(\hat{L} - lN)^a (\hat{W} - wN)^b \ /[g_r(N - N_u^*)]^{a+b} \\
&\quad - \{\frac{\hat{c}_r^I}{N - (1 - d_r)N_u^*} + m_r N^{h_r} + y_r[1 - 2((N - N_u^*)/N)]\}/g_r \\
&\quad - [w/g_r + (\hat{W} - wN)/g_r(N - N_u^*)]q_r \\
&\quad - [l/g_r + (\hat{L} - lN)/g_r(N - N_u^*)][e_r + t_r(N - N_u^*)/N] \\
&\qquad .(22)
\end{aligned}
$$

[3] See also earlier seminal studies of general place-to-place (not necessarily rural-urban) migration by Schultz (1962) and Sjaastad (1962).

Similar to the consideration of per-capita income in economic growth studies, per capita expected net benefit, $(g_u N_u v_u + g_r N_r v_r)/N$, is taken to indicate the expected net benefit for the representative islander—an imaginary urban-rural hybrid. The population size that maximises $(g_u N_u v_u + g_r N_r v_r)/N$, while an urban-rural equilibrium is maintained, is defined to be the island's efficient population size. Recalling the model's specifications, the island's efficient population size is found by solving the following problem:

$$\max_N [(g_u N_u v_u + g_r N_r v_r)/N] \tag{23}$$

subject to a rural-urban equilibrium

$$v_u = v_r \tag{24}$$

where,

$$\begin{aligned} v_u &= f(N) y_u \\ &\quad - \{\frac{\hat{c}_u^I}{d_u N + (1-d_u)N_u} + m_u N^{h_u} + y_u [1 - 2(N_u / N)] + wq_u + (e_u + t_u \frac{N_u}{N}) l\} / g_u \end{aligned} \tag{20'}$$

and

$$\begin{aligned} v_r &= qPA_r (\hat{L} - lN)^a (\hat{W} - wN)^b / [g_r (N - N_u)]^{a+b} \\ &\quad - \{\frac{\hat{c}_r^I}{N - (1-d_r)N_u} + m_r N^{h_r} + y_u [1 - 2(N_r / N)]\} / g_r \\ &\quad - [w/g_r + (\hat{W} - wN)/g_r (N - N_u)] q_r \\ &\quad - [l/g_r + (\hat{L} - lN)/g_r N_r][e_r + t_r (N_r / N)] \end{aligned} \tag*{.(21')}$$

Denoting the model's parameter set as X and the rural-urban combination that satisfies the equilibrium condition (22) as N_r^* and N_u^*, and noting that $v_u(N, N_u^*, X)$ and $v_r(N, N_u^*, X)$ are explicitly obtained by substituting N_u^* into Eq. (20) and Eq.

(21), respectively, the island's efficient population size is $\arg\max\{[N_u^* v_u(N, N_u^*, X) - N_r^* v_r(N, N_u^*, X)]/N\}$. If $d^2 v/dN^2 < 0$ there exists an interior solution, N^o, satisfying

$$v_u(N^o, N_u^*, X)\frac{dN_u^*}{dN} + N_u^* \frac{dv_u(N^o, N_u^*, X)}{dN} = v_r(N^o, N_u^*, X)\frac{dN_r^*}{dN} + N_r^* \frac{dv_r(N^o, N_u^*, X)}{dN} \quad .(25)$$

As there is not a close-form solution, the efficient population-size and its equilibrium rural-urban composition are found through numerical simulations with heuristic assumptions about the values of the model parameters.

4. Simulation's Technique and Parameters

The simulation program uses the *Lagrange* method and incorporates the constraint presented in equation (24) into the objective function portrayed in equation (23) in a quadratic manner, $(g_u N_u v_u + g_r N_r v_r)/N - l(v_u - v_r)^2$, with l denoting the *Lagrange* multiplier and measuring the shadow value of a urban-rural arbitrage for the representative islander. The simulation program has been written in C^{++} programming language under windows operating system, which provides the highest level of programming flexibility. With meaningful intervals, all possible numerical combinations of N and N_u values are used to create a grid in which the first dimension represents N and the second dimension shows N_u. A surface $(g_u N'_u v_u + g_r N'_r v_r)/N' - l(v'_u - v'_r)^2$ is projected on the grid with N' and N'_u revealing the values of the first and second dimensions, respectively. The combination associated with the highest peak in this surface is selected as the solution.[4]

[4] By virtue of equation (3), the value of N'_r is determined by the values of N' and N'_u. Hence, N'_r is not considered as a control variable.

The simulations are performed with predetermined values of some of the parameters and calibrated values of the rest of the parameters that replicate the current (2004) size and urban-rural composition of Australia's population with the proposed model as the expected-personal-net-benefit maximising size and the equilibrium composition. The calibration of the model's parameters takes into account that $y_u = 65{,}000$ dollar, $g_u = 0.4$,[5] $g_r = 0.25$,[6] $f = 0.95$, $q = 0.667$, $q_u = 2.07$ dollar,[7] $q_r = 0.07$ dollar,[8] $w = 120$ cubic metres per person per annum,[9] $\hat{W} = 8{,}000{,}000{,}000$ kiloliters per annum,[10] $\hat{L} = 192{,}050{,}000$ acres,[11] $l = 0.05$ acre,[12] $N_{\max} = 66{,}666{,}667$,[13] $d_u = d_r = 0.5$, $h_u = h_r = 0.5$,[14] $a = b = 0.5$,[15] and $y_u = y_r = 0$.[16] Using these values and the assumptions indicated in the footnotes, the calibrated parameter values obtained by simulating the 2004 population size and urban composition are: $e_u = 5{,}000$ dollar,[17] $e_r = 65$ dollar,[18] $d_u = d_r = 0.5$,

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5 Each urban worker, female or male, is taken to have a sole responsibility for 1.5 dependents.

6 The female and male heads of the farm-hold are taken as constituting a combined unit that generates the revenues, pays the costs and has responsibility for three dependents.

7 Based on an average of sampled Australian urban household's water bills, there is a charge of $ 0.98 per cubic meter of fresh water used plus $ 1.09 of water service and sewerage service per cubic meter.

8 Based on information obtained on water costs from interviewing farmers in New South Walse.

9 Based on a sample average of Australian urban household's water consumption.

10 Obtained by multiplying the sample average annual personal water consumption (120 cubic meters) by the 2004 population of Australia (20,000,000 people) and by the inverse of the current urban sector's water consumption in Australia (1/0.3). As future technological improvements in recycling waist water and desalinating ocean water and the water of the Great Artesian Basin can increase this quantity, this figure represents a conservative assessment.

11 A conservative assumption that only ten percent of Australia's land—768,200 squared kilometres—is habitable.

12 A hundred squared metres, including an equal share in public areas.

13 $N_{\max} = \hat{W} / w = 66{,}666{,}667$ people.

14 Taking the loss of cultural and national cohesion and social harmony to diminishingly rise with the population size for both rural and urban dwellers.

15 Taking, for tractability, the return to scale to be constant and that in an arid, warm island the elasticity of aggregate agricultural production with respect to irrigation water is substantial and possibly as high as the elasticity with respect to land.

16 The setting of $y_u = y_r = 0$ reflects an elimination of sector-based political bargaining power, which is consistent with a normative modelling. Namely, a constrained maximisation of per capita expected net benefit performed by an unbiased and non-discriminating public planner.

17 Equivalent to 0.5 percent loss of value on an urban acre whose current market value is $ 1,000,000.

18 Assuming that urban land and the atmosphere above it are much more intensively used, the environmental damage per acre inflicted by farmers is much less.

$\hat{c}_u^I = \hat{c}_r^I = 33{,}320{,}000{,}000$ dollar,[19] $m_u = 0.4472$,[20] $m_r = 0.8944$,[21] $PA_r = 33$ dollar,[22] t_u = 88,560 dollar,[23] and $t_r = 500$ dollar.[24]

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[19] It is assumed that due to isolation the average urban Australian currently travels abroad for non-business related reasons once every 2.5 years for a period of 30 days and his/her overall costs are $ 4,250 including $ 2,000 airfare and $ 2,250 accommodation, meals and overseas travel expenses (i.e., $ 75 per day, taking into account the economies of scale associated with joint trips of family members). This amount implies that the current isolation cost for a representative urban dweller is $ 1900 per annum. Of course, the figure is much higher for those travelling to distant and expensive destination in Europe and North America and lower for those travelling to Asia. Recalling equation 5, $\hat{c}_u^I = 1900(N_u + d_u N_r)$. Given that the current population of Australia is 20,000,000 and is 96 percent urban, $N_u = 19{,}200{,}000$ and $N_r = 800{,}000$. Assuming that $d_u = 0.5$, $\hat{c}_u^I = 1{,}900(19{,}200{,}000 + 0.5x800{,}000) = \$33{,}320{,}000{,}000$.

[20] It is assumed that the current annual value of the loss of cultural and national cohesion and social harmony is $ 2,000 (about five percent of the per capita income) for any urban dweller. Recalling equation (7) and that the current population is 20,0000,000 and assuming that $h_u = 0.5$, $m_u = 2{,}000/\sqrt{20{,}000{,}000} = 0.4472$.

[21] In view of the higher percentage of support for conservative parties in rural Australia, it is assumed that the current annual value of the loss of cultural and national cohesion and social harmony for a rural dweller is twice the loss for urban dweller--$ 4,000. Recalling equation 8 and assuming that $h_r = 0.5$, $m_r = 4{,}000/\sqrt{20{,}000{,}000} = 0.8944$.

[22] From equation (13), $PA_r = y_r[g_r(N - N_u)]^{a+b} / q(\hat{L} - lN)^a (\hat{W} - wN)^b$. The value of PA_r was computed with the chosen values of a, b q, g_r, $\hat{L}$, and $\hat{W}$, with the 2004 figures of $N = 20{,}000{,}000$ and $N_u = 19{,}400{,}000$, and with revenues $y_r = \$164{,}000$ that are twice the average Australian farm-hold income in 2001-02 in 2004 prices (Table S1, Selected socio-economic measures, Australian Bureau of Agricultural and Resource Economics, Australian Government).

[23] From equation (18), $t_u = c_u^L / [(l/g_u)(N_u/N)]$. Recalling that $g_u = 0.4$, each urban worker has 1.5 dependents and hence providing accommodation for 2.5 people—half an average family. Presently, the average weekly rental cost of urban accommodation for half a family is 206.5 dollar per week, which implies that $c_u^L = 206.5x52 = 10{,}738$ dollar per annum. Recalling further that presently $N_u / N = 0.97$ and that $l = 0.05$, then t_u = 88,560 dollar.

[24] It is consistent with an average return (net of the costs on other hired, or purchased, inputs and self labour) on an acre of arable land of 500 dollar per annum.

5. Employment Prospects and Simulation Results

The simulations of the effects of the urban-rural water-price differential on the efficient population and urban-rural composition of an island similar to Australia are conducted for three scenarios:

A. the probability of urban employment is not affected by the size of the urban population and is equal to the current one ($f = 0.95$);
B. the probability of urban employment decreases with the size of the urban population in accordance with equation (12) and $\tilde{j} = 0.015$; and
C. the probability of urban employment decreases with the size of the urban population in accordance with equation (11) and $j = 0.165$.[25]

In each scenario, the simulations are conducted with the assumption that the full price of urban water is fixed and equal to 2.07 dollar per cubic metre regardless of changes in the population size and in the agricultural water consumption induced by the changes in the agricultural water-price. This assumption suggests, for tractability, a balance, following an increase in the agricultural water-price, between the upward pressure on urban water price generated by the growing urban population and the downward pressure on urban water price stemming from the decline in the agricultural water consumption. The simulation results are summarised in Table 1.

[25] The computation of j and $\tilde{j}$ is consistent with five percent urban unemployment and total population of 20 million: $j = \dfrac{1-f(N)}{N/N_{\max}} = \dfrac{0.05}{20/66.666}$ and $\tilde{j} = \dfrac{1-f(N)}{N_{\max}/N} = \dfrac{0.05}{66.666/20}$.

Table 1: Efficient population size, urban share, expected net benefit and unemployment for various agricultural water prices

Agricultural water price ($) **Urban water price ($)**	**0.07** **2.07**	**0.014** **2.07**	**0.30** **2.07**	**0.40** **2.07**	**0.80** **2.07**	**1.25** **2.07**
Scenario A						
Population (millions)	20	26	32	36	38	48
Urban population share	0.968	0.975	0.981	0.984	0.989	0.995
Expected net benefit for urban workers and farmers ($)	40,356	40,609	40,562	40,455	40.349	39,915
Urban unemployment rate	0.05	0.05	0.05	0.05	0.05	0.05
Scenario B						
Population (millions)	20	27	38	44	46	47
Urban population share	0.968	0.976	0.984	0.987	0.991	0.995
Expected net benefit for urban workers and farmers ($)	40,356	41,610	42,049	42,029	41,969	41,915
Urban unemployment rate	0.05	0.04	0.03	0.02	0.02	0.02
Scenario C						
Population (millions)	20	14	23	20	17	19
Urban population share	0.968	0.961	0.975	0.974	0.979	0.989
Expected net benefit for urban workers and farmers ($)	40,356	40,612	40,231	40,535	40,620	40,468
Urban unemployment rate	0.05	0.03	0.06	0.05	0.04	0.05

6. Conclusion

The simulation results illustrate the central role of the effect of immigration on the prospects of urban employment in determining the island's efficient population size. As long as the probability of urban employment is not diminished by population growth (i.e., scenarios A and B), a decline of the urban-rural water-price differential from the current huge level of two dollars will largely increase, albeit in diminishing numbers, the island's population without changing the expected net benefit for urban dwellers and farmers. A rise of about seventy-three cents, in scenario A, or of a mere twenty-three cents, in scenario B, of the agricultural water price may facilitate the doubling of the population of a large island like Australia and reaching a medium-size international rank through immigration without compromising the current prospects of employment and net benefits for residents, environmental benefits included.

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