How Much More Rent Could Have Been Extracted From Nauru's Phosphate Deposits?

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Keywords: *Phosphate mining; Quadratic programming; Dynamic optimization*

EXTENDED ABSTRACT.

In 1900, one of the highest grades of phosphate rock ever found was discovered on Nauru. In 1919 the Nauru Island Agreement was signed by Britain, Australia and New Zealand, establishing the British Phosphate Commission (BPC). Mining under the Commission started in 1922.

The objective of the BPC was to export plentiful amounts of phosphate at the lowest possible price to the three signatory countries. Nauru's phosphate was essential for the development of the large-scale agricultural and pastoral industries in Australia and New Zealand.

When Nauru gained independence in 1968, the Government of Nauru took over the phosphate mine by establishing the Nauru Phosphate Corporation (NPC) to replace the BPC.

The problem facing Nauru from 1922, through the war years and on to independence in 1968 and more recent times in mining phosphate reserves is investigated, with the benefit of hindsight. Account is taken of the changing institutional arrangements and goals of mining, and the interests of importing countries such as Australia, Britain and New Zealand, in boosting agricultural production.

The aim of the paper is to determine how profiles of annual extraction volumes would have differed under alternative policy objectives, conditional on optimizing behaviour and perfect knowledge about assumed future demand and supply functions, and the extent of the phosphate reserves. Three dynamic optimisation problems are formulated and solved for the following three objective functions, with respect to annual extraction, subject total amount mined being less than or equal to the initial stock: (A) maximising the present value of rents from extraction (returns to Nauru only); (B) maximising the present value of the sum of extraction rents and consumer surpluses (returns to Nauru, Britain, Australia and New Zealand combined); and (C) maximising the present value of the sums of extraction rents and consumer surpluses for the years before independence, and extraction rents only for the years after independence. Optimal extraction paths and values for all three objective functions are presented for each of the three models, and compared with corresponding values for the actual extraction profile over time. Sensitivity analysis is conducted for inelastic and elastic demand for phosphate schedules.

Compared with model A (maximising returns to Nauru), model B (maximising returns to Nauru, Britain, Australia and New Zealand combined) gave modelled annual extraction and level and distribution of returns between Nauru and importing countries closer to actual levels, for inelastic demand. Because Nauruan phosphate was essential for Australian and New Zealand crop production historically (there were no chemical or geographic substitutes), demand is much more likely to have been inelastic than elastic.

Unlike the results for models A and C, model B results exhaust all phosphate available over the planning horizon, and captures the much higher proportion of total surplus accruing to farmers in the importing countries. Model C, which has the same objective function as B up to independence over the first and longer part of the planning horizon to 1998, produces similar results to B's, but has a total surplus across all parties closer to the actual total surplus.

It is concluded that the results from the simple models described in the paper do give some insight into the motivations and achievements of the mining policies pursued by the BPC and the NPC.

1. INTRODUCTION

Nauru has had a bad press recently in terms of disastrous investment of rents from its major asset, phosphate rock during the period since independence in 1968 (Hughes, 2004). Another question is the efficiency and equity of the extraction path followed since 1922. It is the question addressed in this paper.

The aim is to determine how profiles of annual extraction volumes would have differed under alternative policy objectives, conditional on optimizing behaviour and perfect knowledge about assumed future demand and supply functions, and the extent of the phosphate reserves. Modelled extraction paths over time are compared with the actual extraction paths.

The alternative policy objectives considered are maximizing the present value (PV) of benefits to Nauruans (measured by mining profits or producer surplus) and to the consumers of the phosphate, Australian and New Zealand farmers (measured by consumer surplus). Estimates of producer and consumer surplus depend on the extracted volume and the associated price of phosphate and extraction costs. These are discussed in Section 3.

2. DISCOVERY AND EXPLOITATION OF NAURU'S PHOSPHATE

In 1900, one of the highest grades of phosphate rock ever found was discovered on Nauru. This discovery boosted Nauru's economic prospects immeasurably. Phosphate mining began in 1907 under a German administration, but after World War I, Nauru was given to Australia to administer (Howard 1991, p.9). In July 1919, the Nauru Island Agreement was signed by Britain, Australia and New Zealand, establishing the British Phosphate Commission (BPC), which held title to the deposits and set the price of phosphate. The BPC started mining in 1922. Phosphate exports were to be distributed at the rate of 42 per cent to Britain, 42 per cent to Australia and 16 per cent to New Zealand. (Howard 1991, p.10).

The Nauruans were essentially left out of the Nauru Agreement. The objective of the newly formed BPC was to export "the largest amount of phosphate available at the lowest possible price" (Williams and McDonald 1985, p. 150). Each country's allotment was for home consumption and not for export.

Nauru's phosphate has supported the large-scale nature of agriculture and pastoral industries in Australia and New Zealand. Because Australia has strongly leached, highly weathered, low fertile soils, the potential yields of crops and pastures could not have been realised without the addition of phosphate fertilisers.

Adding phosphate to Australian soils has also been essential to the growth of clover as a pasture legume. Clover remedies the nitrogen deficiency of Australian soils and helps maintain soils' organic matter and structure. This is perhaps even more so for New Zealand where the use of sown pastures instead of natural grasslands was the basis of the nation's export trade and domestic economy.

For the United Kingdom, being party to the Agreement was less about sourcing actual phosphate and more about gaining the leverage it provided to build its negotiation power with its closer suppliers in Morocco and Florida.

In 1967, a new Nauru Agreement was signed, granting Nauru control of the phosphate industry. In return, Nauru guaranteed an exclusive supply of phosphate to Australia and New Zealand at annual rate of two million tons per year. Britain had stopped buying Nauru phosphate in 1966 when the price increased following renegotiation of royalties.

When Nauru became an independent nation in January 1968, the Government of Nauru took over the mine by establishing the Nauru Phosphate Corporation (NPC) to replace the BPC. The price of Nauru phosphate was no longer held below the world price. Interestingly, the level of Australian and New Zealand consumption of Nauru phosphate remained steady despite having to pay at the higher world price.

This situation continued until more recent times, when Australia began to source most of its phosphate from new markets, such as Mt Isa in Queensland, as well as Indonesia and China.

3. MODEL DESCRIPTION

3.1 Price Determination

The historical time profile of phosphate prices over the modeled planning horizon is shown in Figure 1. Prices drifted down for many years from 1922, but dramatically peaked in 1974 after the first oil price shock (Howard, 1991, p.14), before drifting down again.

Each recorded phosphate price, converted to 1990 prices ($/t)[1], $\hat{p}_t$ and export volume (t'000)[2], $\hat{q}_t$ for year *t* is assumed to be one observation on an annual linear inverted demand schedule:

$$p_t = a_t + b_t q_t \quad (1)$$

where a_t and b_t are the year-specific constants. The schedule can be used for finding p_t for some export volume other than the one observed. The price elasticity of demand for each observed price-quantity observation ε is assumed to be the same for all years 1922 to 1998. This makes the demand function constants, for each year *t*, $\hat{p}_t(1-1/\varepsilon)$ and $\hat{p}_t/(\varepsilon\hat{q}_t)$ respectively. Because there are no estimated Australian and New Zealand demand elasticities for phosphate over the period, sensitivity analysis is reported for values of -1.5 and -0.5. The latter value is the more likely, because there is good reason to suppose that demand by Australian and New Zealand farmers was price-inelastic. Nauruan phosphate was essential for crop production, and there were no chemical or geographic substitutes.

The consumer surplus generated for any consumption level q' is the excess of total willingness to pay for q' over total market payment, given by

$$CS\{q'\} = -bq'^2/2 \quad (2)$$

3.2 Extraction Cost Determination

Extraction costs depend on various factors such as fixed costs of capital and equipment maintenance, variable costs a function of the amount extracted, the size and quality of the phosphate stock remaining for exploitation, and changes in extraction technology over time. Unfortunately, there are no data available enabling estimation of this breakdown of costs. Indeed, there are no direct data on the total annual costs of mining by BPC and NPC. For present purposes annual BPC annual total mining costs (1922 to 1967) are estimated as export revenue less payments of phosphate royalties for administration and Nauruan community services, based on Viviani (1970, Table 11). This assumes that no rents were made after mining costs and royalties, consistent with the calculation of BPC costs, 1948 to 1967, by the Centre for International Economics (1990, Table A2).

Post-independence mining costs incurred by NPC have been estimated as on average 28 per cent of export revenue over the years 1977-78 to 1988-89 (Centre for International Economics, 1990, pp. 188-189). This percentage is used in the model for the post-independence years 1968 to 1998.

Estimated total extraction costs (*TEC*, 1990 $'000) for the years 1922 to 1998 were regressed on combinations of the independent variables: quantity extracted (*q*, t'000), quantity of phosphate remaining, year number (*t* = 1 for 1922), and a 0/1 dummy variable (*d*) for years before/after independence. Cost function (2) with the two coefficient sets shown in Table 1 were selected on adjusted R^2 and *t* statistics.

$$TEC = \beta_0 + \beta_1 q + \beta_2 t + \beta_3 d \quad (3)$$

Table 1. Total extraction cost coefficients*

β_0	β_1	β_2	β_3	Adjusted R^2
Set 1				
10,277	28.2	-298		0.533
2.67	*8.93*	*-3.51*		
Set 2				
11,930	28.1	-393	5,243	0.531
2.75	*8.87*	*-2.77*	*0.84*	

*t statistics in italics

The β_1 coefficient in (2) is the constant marginal cost of extraction, the key cost coefficient for determining producer surplus and optimal annual extraction in the model. Table 1 shows marginal cost to be $28.2/t (1990 $) in the first coefficient set, and is used in the modeling. Set 2 shows a very similar β_1 in magnitude and high statistical significance.

[1] **Data sources:** Viviani (1970, Table 8) for Austalian prices 1921-1967; International Monetary Fund (2005) for US prices 1968-1998; Vamplew (ed.) (1987, p.244) for exchange rates 1964-1984; Reserve Bank of Australia for exchange rates 1985-1998; Australian Bureau of Statistics (2005) and (1961, 1957) for CPI for converting prices to 1990 real prices.

[2] **Data sources:** Viviani (1970, Table 8) for 1922-1967, and United States Bureau of Mines (1968-1998) for 1968-1998.

The producer surplus generated for any production level q' and corresponding price p' is the excess of market revenue over total variable extraction costs, given by

$$\begin{aligned} PS\{q'\} &= (p' - \beta_1)q' \\ &= (a - \beta_1 + bq')q' \end{aligned} \qquad (4)$$

3.3 Real Rate of Discount

The analysis is conducted with real prices and costs in 1990 dollars, which means that the relevant discount rate is the real rate rather than the observed market rate which includes the rate of inflation. The real risk-free discount rate for the period 1922 to 1998 was calculated from the money yields from 10-year Australian government bonds[3] offered each year and the Australian Consumer Price Index (Australian Bureau of Statistics (2005) and (1961, 1957)) over the period. The average annual growth rate for the cumulative real growth of $1 invested in 1922 to 1998 was found to be 2.18 per cent per annum, and used as the discount rate. A riskless rate is used because the phosphate stock in 1922, and the demand and cost functions to 1998 are assumed known with certainty in 1922, and most royalty payments from BPC and NPC were invested in long-term trust funds.

3.4 Objective Functions

Three objective functions were used. The first (A) was the PV of the sum of annual producer surplus from estimated BPC and NPC net revenues based on historical or modelled annual phosphate exports from 1922 to 1998. This focuses solely on the surplus accruing to BPC and NPC, and to Nauruans, to the extent that the surplus is paid as royalties and invested in trust funds.

The second (B) was the PV of the sum of BPC and NPC producer surplus plus consumer surplus accruing to the buyers of the phosphate, namely farmers in Australia, New Zealand and the UK. This is of interest because it is the function to maximize to determine the economically efficient time-profile of exports. This is an outcome which would be expected if BPC or NPC were one player in a perfectly competitive industry. In fact, they are more closely approximated as monopoly players given the high per unit shipping costs of phosphate rock. However, before independence it is clear that supplying farmers with plentiful amounts of phosphate at lowest price was an important goal of the BPC, as well as the provision of services for Nauruans. By modeling the BPC as setting exports to maximise this objective function the BPC is placing equal weighting on producer and consumer surplus. This may be a reasonable objective function if BPC in 1922 expected to control mining to 1998 and beyond, but also if sale of the mining concern were contemplated when Nauru gained independence at some time before 1998. In the latter case it would have been reasonable to place a market value on the concern at independence equal to the PV of producer and consumer to 1998, and this value is automatically include in the objective function.

The third objective function (C) is the PV of the sum of pre-independence producer and consumer surplus from 1922 to 1967, plus the sum of post-independence producer surplus from 1968 to 1998. This assumes that it is known in 1922 that Nauru becomes independent in 1968, and that the company taking over phosphate mining will be able to exploit the reserves as a monopolistic profit maximiser, rather that as a competitive player.

3.5 Initial Phosphate Stock

Phosphate reserves at the start of 1922 are assumed to be the amount actually mined over the modeled planning horizon from 1922 to 1998, 75,672 thousand tons.

3.6 Formulation of optimal extraction path problems

The problem of determining the extraction path over *T* years that maximizes the PV of the sum of consumer and producer surplus is formulated, using (2) and (4), as

$$\max_{q_1 \ldots q_T} \sum_{t=1}^{T} (a_t - \beta_1 + b_t q_t / 2) q_t / (1+r)^t \qquad (5)$$

$$\text{subject to } \sum_{t=1}^{T} q_t \le Q_0$$

where q_t is the quantity extracted in year *t*, *r* is the annual rate of discount, and Q_0 is the initial stock of phosphate. The problem of maximizing the PV of the sum of producer surplus is the same as (5), but with (4)

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[3] **Data sources**: Personal communication from L.Rafferty, Senior Information Officer, Reserve Bank of Australia for 1921-1968, Reserve Bank of Australia (2005) for 1969-1998

substituted for the numerator of the objective function.

The problems are quadratic programming problems and are solved using the Solver tool in an Excel spreadsheet. The optimality conditions are discussed in resource economics texts such as Hartwick and Olewiler (1986).

4. RESULTS

For an elasticity of demand of -0.5, the optimal time-profiles of annual extraction for maximum PV of producer surplus (A), and of producer plus consumer surplus (B), can be compared with the actual extraction path in Figure 2. No extraction is allowed on the optimal paths during the period 1941 to 1947 when extraction was disrupted due to WWII. Annual extraction on profit-maximising path A lies below the actual extraction path, taking advantage of the resulting higher prices. Welfare-maximising path B several times crosses over the actual extraction path. Peaks on the optimal paths coincide with peaks on the actual path reflecting the modeled demand-schedule shifts.

Total extraction and all objective-function values for actual and optimal extraction paths are shown in Table 2, for elasticities of demand of -0.5 and -1.5. For elasticity = -0.5, consistent with Figure 2, total extraction for profit-maximising path A is 46 million tons, significantly less than the 76 million tons actually extracted. In order to maximize profit, quantity extracted is reduced to make demand elastic and marginal revenue positive. This means that the across-years total stock constraint is not binding, and that extraction in each year is at the profit maximizing level, independent of extraction in other years.

Consumer surplus, a measure of the benefits to importers of Nauru's phosphate, is much higher under the actual extraction path for elasticity -0.5 than under the profit-maximising path A, the path which would maximize the welfare of Nauruans. However, importers' welfare would have been even greater under welfare maximization (path B), or competitive conditions.

Total extraction for path C (producer and consumer surplus maximized before independence, and producer surplus after independence) is 64 million tons. Again the total stock constraint is not binding. This means that over the pre-independence years extraction is at the level that price equals marginal extraction cost, and that profit or producer surplus is zero because marginal extraction cost does not vary with extraction. All benefit is in consumer surplus to importing countries.

For elastic phosphate demand at -1.5, the total stock constraint is again not binding under profit maximization, with only 64 million tons extracted. Under the actual extraction path the welfare of importing countries is lower than Nauruan welfare in both relative and absolute terms.

Across both elasticities, it is noticeable that optimal extraction paths B and C do not result in optimal objective function values much greater than those under the actual extraction paths.

5. CONCLUSIONS

Under the BPC management arrangements, prices were deliberately distorted—the low price and high production policy of the BPC was not a profit maximising exercise. Rather than delaying production in preparation for higher prices, the BPC set prices lower to raise consumer surplus flowing to farmers in Britain, Australia and New Zealand. The PV of producer surplus over the period 1922 to 1998 was 64 per cent of the modeled maximum for inelastic demand ($\varepsilon = -0.5$), and the amount actually extracted (76 million tons) was much greater than the modeled optimum of 46 million tons.

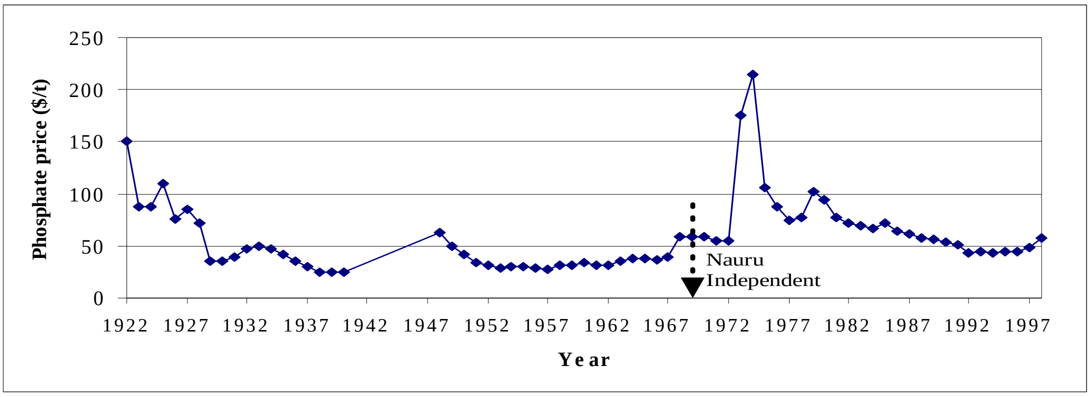

Figure 1. Historical real phosphate prices (A$/t, 1990 prices)

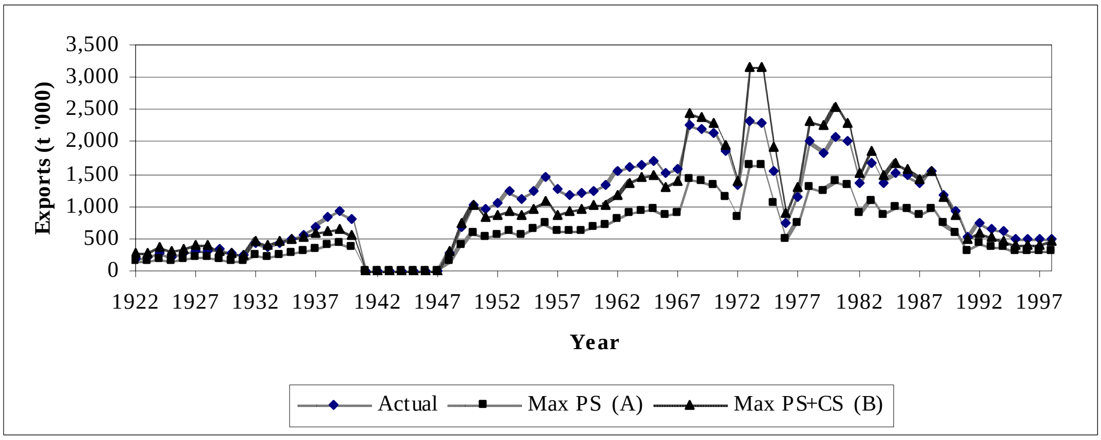

Figure 2. Actual and optimal extraction paths for elasticity of demand = -0.5

Table 2. Present value payoffs (1922) from actual and alternative optimal annual extraction paths for elasticities of demand = -0.5 and -1.5

		Elasticity of demand = -0.5				Elasticity of demand = -1.5			
		Actual	Maximise			Actual	Maximise		
			Pre Independence 1922-67				Pre Independence 1922-67		
			PS	PS + CS	PS + CS		PS	PS + CS	PS + CS
			Post Independence 1968-98				Post Independence 1968-98		
			PS	PS + CS	PS		PS	PS + CS	PS
			(A)	(B)	(C)		(A)	(B)	(C)
Total q^*	t m	76	46	76	64	76	62	76	76
CS	$ m	1,849	740	2,297	1,456	616	510	1,254	820
PS	(A) $ m	954	1,480	601	1,002	954	1,020	601	809
PS + CS	(B) $ m	2,803	2,220	2,898	2,458	1,570	1,530	1,855	1,629
Pre PS+CS + Post PS (C)	$ m	1,675	1,719	1,300	1,957	1,194	1,152	887	1,280

*Total phosphate available is 76 m t.

The PV of welfare (producer plus consumer surplus) flowing to both Nauruans and overseas farmers was very close to the modeled maximum (for $\varepsilon = -0.5$) of 96 per cent (85 per cent for $\varepsilon = -1.5$). The welfare maximising model produced extraction profiles closest to actual profile. Compared with results for maximizing objective C (PV of producer plus consumer surplus before independence, plus PV of just producer surplus thereafter), the objective functions judged most likely to match historical objective functions, the objective-function value is 86 per cent (for $\varepsilon = -0.5$). Modelled total extraction was only 64 million tons. Comparable results for $\varepsilon = -1.5$ are 93 per cent and 76 million tons respectively.

The results from the simple models described in the paper do give some insight into motivations behind past extraction policies of Nauru's phosphate resource. There is bound to be a gap between modeled results and actual results, particularly because the models determine optimal extraction paths taking stock, and demand and cost functions as known with certainty. An alternative modeling approach would be to have each model determine extraction for each year from 1922 to 1998 sequentially, based on the first year's extraction of the optimal path to the end of 1998 assuming the current year's observed price and quantity would remain unchanged to 1998.

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