DISCUSSION PAPERS

ALUMINIUM AND POWER

P. van Moeseke

Discussion Paper No. 78

November 1983

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ISBN: 0 918638 79 9

ISSN: 0725-430X
## TABLE OF CONTENTS

<table>
<thead>
<tr>
<th>Abstract</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Introduction</td>
<td>1</td>
</tr>
<tr>
<td>2. Export Efficiency and Exchange Premium</td>
<td>2</td>
</tr>
<tr>
<td>3. Upweighting Foreign Exchange and Capital-Intensive Development</td>
<td>4</td>
</tr>
<tr>
<td>4. Distortion: Income Effect or Deadweight Loss</td>
<td>6</td>
</tr>
<tr>
<td>5. Risk Allowance</td>
<td>10</td>
</tr>
<tr>
<td>6. The Rising Marginal Cost of Electricity</td>
<td>12</td>
</tr>
</tbody>
</table>

References                                    | 13   |

**FIGURES**

<table>
<thead>
<tr>
<th>Figure</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Figure 1</td>
<td>Capital-Intensive Expansion</td>
<td>9</td>
</tr>
<tr>
<td>Figure 2</td>
<td>Distortion</td>
<td>9</td>
</tr>
<tr>
<td>Figure 3</td>
<td>LMC Electricity</td>
<td>14</td>
</tr>
</tbody>
</table>
ALUMINIUM AND POWER*

P van Nooije

Abstract

We draw attention to a number of key theoretical aspects and pitfalls in the evaluation of major projects, such as smelters, which are highly capital-and energy-intensive as well as export-oriented.

The upweighting of foreign exchange, and the cost of distortion are considered. In particular export efficiency is introduced as the key criterion in the appraisal of such projects. The efficiency of some recent smelter proposals was between 36 and 30 cents in the dollar. A correct power price is essential. Contrary to current accounting practice hydro-power is subject to depletion pricing.

UNIDO or the World Bank should take a concrete step towards the New International Economic Order by listing objective estimates of the long-run marginal cost of power in potential host countries.

* Australian National University and Massey University, New Zealand. The paper was written during my tenure of the Professorial Fellowship in Economic Policy of the Reserve Bank of Australia, whose generous support is gratefully acknowledged.
1. Introduction

The main thrust of this presentation is that the worldwide reallocation of smelter capacity ought to be coordinated in view of the serious planning errors made in the recent past, leading to the scrapping or mothballing of five planned smelters in Oceania alone.8

The address therefore concludes with an urgent appeal for the adoption of a major relocation criterion. Since adequate information is the primal prerequisite of the competitive market this coordination can be left to market forces if location is based on correct energy costing. Remembering that aluminium is essentially solid electricity, I would like to avail myself of this Forum to propose that an international agency like UNIDO or the World Bank start listing independent estimates of the long-run marginal cost of power in all potential host countries. This would save both them and the companies concerned risk and expense, relieve pressure on governments to negotiate uneconomic deals for political reasons and promote efficient worldwide smelter location.

The proposed measure is purely indicative, rather than coercive, and therefore entirely consonant with free competition. The measure would further constitute the first concrete step towards the New International Economic Order within a major commodity market.

Relocation will further have to take into account the expert efficiency of aluminium production from the prospective host nations' point of view, as well as the long-run marginal cost of the supposedly cheap power they have to offer. It is already clear that correct economic analysis puts the industrial nations and classical producers at a lesser comparative disadvantage than was thought.

8Aramoana in New Zealand; Bunbury, Bundaberg, Lochinvar and Portland in Australia.
The severe cutbacks in planned smelter capacity in Australasia, for instance, are at least partly due to economic reappraisals, such as my smelter reports [21,22,23], written from the national, rather than the corporate, point of view, and which evaluated the net benefits of a multinational enterprise requiring huge investment in power plant by the host country. If the industry majors are to avoid expensive relocation mistakes they will have to make sure planned greenfield smelters stand up to economic analysis.

Relocation plans, in the wake of the oil crises, from the industrial to the peripheral nations, essentially marked a tradeoff between cheap power and market distance, the cost of stricter environmental controls in industrial areas being a subsidiary factor. On the local level, in the absence of overall economic impact studies, feasibility reports commissioned by both companies and local governments stressed regional employment and gross earnings from electricity payments.

It turned out that the real cost had been vastly underestimated. Specifically:

(1) The amount of gross foreign earnings is by itself meaningless. What counts is export efficiency, i.e. domestic value added per unit of net foreign earnings.

(2) Justification by upweighting foreign exchange can be shown to involve a logical error except in the unlikely event that built-up surplus power is already available.

(3) The extremely capital-intensive imports required for both smelter and power capacity should be seen against both the central trade and neoclassical production propositions of economic theory.

(4) Several basic theoretical errors have repeatedly been made in estimating the economic welfare cost of power to the nation.
It is erroneous, inter alia, to cost extra capacity for a giant baseloader, to be supplied on top of present peak demands, at standard concessional rates. Furthermore, in the case of hydro-power plants, it is essential to know that hydro-electricity is a twin resource, viz. hydro-energy, which is renewable as long as it rains, and hydro-power, which is depleted as the remaining suitable river valleys get damned and the corresponding power blocks auctioned off in very long-term contracts. What a smelter really buys is precisely hydro-power. And competition with fossil fuels in any case subjects its long-run social cost to the rules of depletion pricing.

Finally, increased recycling, as well as technical innovation such as Mitsui's direct-reduction process, lend even more weight to the above arguments.

2. Export Efficiency and Exchange Premium

We define the annual export efficiency of an export operation as the positive fraction

\[ E = \frac{\text{Net Foreign Earnings (NFE)}}{\text{Domestic Value Added (DVA)}} \]

which measures the efficiency (ideally \( E = 1 \)) at which domestic resources are traded.

If one puts \( q = 1/E \) the net annual social benefit of the project is

\[ (1-q)NFE = NFE - DVA \]

which is, of course, negative if the project is inefficient \( (E < 1) \).

If (2.1) is negative, \( q \) measures the shadow price of foreign exchange required, \textit{ceteris paribus}, to make the project break even; equivalently, \( q-1 \) is then the required premium on foreign exchange. The \textit{ceteris paribus} clause is essential as pointed out below.
For concrete examples of the measurement and use of these concepts the reader may refer to my reports [21,22] on two smelter projects—since cancelled—in New Zealand with estimated efficiencies of $E = 35.6\%$ ($q = 2.8$), respectively $E = 50\%$ ($q = 2$). This means that, under then prevailing conditions, domestic resources earned, dollar for dollar, nearly thrice, respectively twice, as much foreign exchange in traditional export activities, or that, at the then rate of exchange, 2.8 dollars' worth, respectively 2 dollars' worth, of domestic inputs were required per dollar of foreign exchange earned. It is pointed out in Section 3 that upweighting of foreign exchange in this case involves a logical error.

Computing the export efficiency $E$ is straightforward when the entire smelter output is to be exported as is the case for new smelters in Australia and New Zealand, where existing and committed capacity already far exceeds local demand.

Let export of value $y > 0$ absorb inputs of value $x_j > 0$ ($j = 1,...,n$) with foreign content $m_j$ (0 $\leq$ $m_j$ $\leq$ 1, all $j$), where $m_j = 1$ if all of input $j$ is imported and = 0 if it is a purely domestic factor. In particular if $j$ refers to capital then $m_j$ is the fraction of return on capital paid overseas. Further, if $x_j$ is depreciation then $m_j$ corresponds to the foreign-owned fraction of equity capital. The exchange rate is assumed to be in equilibrium.

Define:

$$\text{Net Foreign Earnings (NFE)} = y - \sum_j m_j x_j$$

$$\text{Domestic Value Added (DVA)} = E(1-m_j)x_j$$

The concept of export efficiency used in this paper is

$$E = (y - \sum_j m_j x_j) / E(1-m_j)x_j = \frac{\text{NFE}}{\text{DVA}}$$

where it is assumed, trivially, that \(\text{NFE} \geq 0\), \(\text{DVA} > 0\).
Clearly \( E \leq 1 \) according as \( y \geq \sum_{j} x_j \) so that market value informs efficiency, which equals at least 1 (or 100%) if the operation at least breaks even.

The formula is, of course, more involved if part of the output is sold in the home market.

3. Upweighting Foreign Exchange and Capital-Intensive Development

Note that the shadow price of foreign exchange is determined ex post, and is a notion very different from an ex ante and arbitrary premium often advocated by planning officials. Given existing trade restrictions the true shadow price might, in the UNIDO and LMBST approaches \([4, 9, 12, 24, 25, 27]\), be estimated ex ante by the weighted domestic-to-border price ratios of tradables in the marginal trade bill under a number of assumptions including given relative commodity prices.

But a major project affects relative resource prices so that naive shadow pricing involves a logical error. This is easily demonstrated, given the official objective of maximizing the project's net foreign earnings. Upvaluing the latter by a factor \( q \) implies that prices of domestic inputs should be upvalued by the same factor \( q \) so that the operation is nugatory since both numerator and denominator in \( E \) are multiplied by \( q \).

Denote aluminium production by \( a \), NFE by \( n(a) \), and the muple of resources used by \( R \). As \( a \) and \( n(a) \) are proportional to the amount of resources used, by the duality theorem of homogeneous programming (Eisenberg \([6]\) = Koesteke \([16, 19]\)) the optimal output \( a^* \) satisfies \( n(a^*) = v^* R \), where \( v^* \) is the muple of resource shadow prices (rents). It follows at once that upvaluing \( n \) by a factor \( q \) yields \( qn(a^*) = (qv^*) R \).
While this observation is immaterial for redundant factors it definitely applies to electricity: and the DVA of this factor alone is of the same order of magnitude as total NFE. This is an illustration of one of the two main scarce-factor propositions in trade theory, viz. the Stolper-Samuelson theorem, which implies that an increase in the price of (or imputation of a premium or subsidy to) a commodity (aluminium) increases the value of the factors intensively used in its production (electricity). The duality theorem, however, allows us to quantify this purely qualitative statement with precision.

By any standard aluminium smelting is one of the most capital- and energy-intensive major industries and hence among the least labour-intensive.

Investment was about $1m per employee in 1979-80 [21, 22] or some 27 times the $36,252 average for 19 major British industries (The Economist, 15 March 1980). Even this figure underestimates total investment by excluding public funding of road and harbour facilities (quite apart, of course, from the required additional electric capacity). It is noteworthy that gross sales per job, for instance, are about 13 times higher than for the US aerospace industry [22], which one would think of as particularly capital-intensive.

The standard complaint about developing nations' overvalued exchange rates cum investment incentives is the distortion induced by thus subsidizing capital costs relative to labour costs. Upweighting foreign exchange, hence capital cost, is designed precisely to counteract this

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a The theorem is an early instance of the Le Chatelier effect (Leblanc and Moussaka [11] in economics.

b The SUS and $NZ were close to parity at the time (1979-80) of the smelter proposals.
effect in favour of less capital-intensive projects, contrary to common official practice. Advocating large, capital-intensive projects while simultaneously upweighting borrowed capital in an economy with surplus labour strains commonsense, accelerates inflation and runs counter to both neoclassical production theory and the scarce-factor propositions.

This is readily shown under standard assumptions. The isoquants of figure 1 represent HNP levels\(^4\); the slopes in any given point measure the ratio - w/r (where w denotes the wage rate, r the return on capital). From the present position a, access to a higher income level may be labour-intensive (in i), balanced (in b), or capital-intensive (in c). Since r is an international given (so-called 'small country' assumption) the move to c is efficient only if the real wage is upvalued rather than downvalued. At a constant real wage the capital-intensive move is clearly inefficient (isocont cuts isoquant) since the same income may be realized by employing \(\text{ch}^1\) more labour while borrowing \(\text{ch}^2\) less capital than in c, and avoiding inflation \(\text{cc}^1\). On the other hand, it is the labour-intensive move to i that reflects the relative upweighting of foreign exchange and downweighting of labour.

This conclusion is an illustration of the second scarce-factor proposition, the Rybczynski theorem, whereby overendowment of one factor (labour surplus) ought to expand the industry that absorbs it relatively intensively. It has received strong empirical support in findings by, inter al., the World Bank [13,29] and the MNER [10], which have warned

\(^4\)The isocont lines (supports) represent the dual of HNP, viz. NI at factor prices.
Figure 1 - Capital-Intensive Expansion

Figure 2 - Distortion
repeatedly against overemphasis on wast capital-intensive projects, so-called white elephants, in developing countries. The 1979 World Development Report [29] rightly complains that:

"Despite their obvious abundance of labour, many developing countries have encouraged capital-intensive industrialization ... by artificially lowering the price of capital to the modern private sector. Subsidized interest rates, allowances for accelerated-depreciation, tax holidays, overvalued exchange rates, and facilities for duty-free imports of capital have enhanced the profitability of capital-intensive investments and often encouraged enterprises to economize on labour rather than on capital."

In New Zealand Philpott and Stroombergen's [26] PEP model indicated that the 1980-85 major energy projects may,

"If anything, (be) deleterious to employment [because of their] very low labour intensity and high import intensity and the fact that the substantial block of investment involved, reduces resources available for other and more employment creating types of investment."

4. Distortion: Income Effect or Deadweight Loss

Comparing two alternatives by straightforward cost-benefit analysis at given prices is acceptable for investment plans that are small relatively to the economy (construction of a road bypass, say) but simplis- tic in the case of major projects. The latter imply a considerable shift along the opportunity frontier (from position 1 to position 2 in fig. 2), and, under standard assumptions, a corresponding drop in real income at present prices. (Unless the frontier expands - but if there is a net loss as in the low-efficiency examples of section 2 the reverse holds.)
The figure graphs the frontier in the space of inputs $x$ (electricity) and $y$ (real index of all other inputs), where $\Delta x$ represents the increase in electricity use and $\Delta y$ the corresponding drop in real NI at current factor prices. This cost is a "pure" distortion and is apart from, and in addition to, subsidy $S$ which supplements payments $C$ at the low rate (dotted slope) charged to the smelter Consortium. It prescinds the higher marginal cost (slope of frontier in 2) that "should" prevail in position 2 or the possibility that through inefficient reallocation the distortion is even greater through contraction of the opportunity frontier (position 2').

If one solves $y = g(x)$ from the transformation curve $f(x, y) = 0$ of fig. 2 the magnitude of $\Delta y$ can be approximated by the second term,

$$
(4.1) \quad \frac{1}{2} \frac{\partial (\Delta x)}{\partial (\Delta y)} g''(y_0)
$$

of a Taylor series, where $g''$ is the rate of change of marginal cost (MC) in cents/unit$^2$ (cents per unit squared). Since we face a rising average cost (AC) curve the increase in the MC of electricity due to smelter expansion rises even faster (twice as fast, in linear approximation). In the New Zealand context [22] if the cost increases by n cents for a production increase $\Delta x$ of some 4,500m units (or kWh) per annum then, by (4.1), $\Delta y = 22.5 n$ (in $\Delta n$) or $22.5 m$ ($\Delta m$) for a 1c (2c) increase in MC (corresponding roughly to a $\frac{1}{2}$c (1c) increase in AC.) These amounts may be compared to the $50m per annum deadweight loss Court [2] arrives at for a 500MW capacity increase (which, in his article, refers to errors in power forecasts), or roughly the immediate requirement for new capacity, viz. third potline at Aluf, plus second smelter, had the latter gone ahead.
5. Risk Allowance

The vast commitment of resources to just one primary product, a volatile metal at that, is a great risk, particularly for a small economy. The risk is compounded by the high energy content of the inputs. To omit the risk allowance from the quantitative appraisal of projects of this size is unacceptable.

Risk-efficient decisions are guided not just by expected value, which has been the sole criterion so far but by a weighting of, for instance, both expectation and standard deviation of net returns (truncated minimax [15], Markowitz efficiency). Relative weights in the range 0.5 - 1.5 for the standard deviation appear reasonable on both theoretical and empirical grounds [17,18]. A coefficient of variation of average annual aluminium prices of at least 7% around the trend line seems realistic but margins on semis vary more widely. Even if one takes only this variation into account a conservative decision, attaching a unit weight to the standard deviation, would not be based on expected value but on a 7% risk discount, say, which by itself exceeds total labour cost, for instance.

The coefficient of variation of average annual US producer prices 1960-73 (with no discernible trend) is 7.12%. Following the oil crisis it becomes 20.09% (but only 2.31% around the trend) for 1974-79. The coefficient of variation of three-monthly LME averages January 1978-February 1981 is 17.14% around the trend line.\[a\]

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\[a\] Primary US price leadership held until the introduction of the LME aluminium contract in October 1978 and the imposition of statutory price guidelines in 1979.
Actually, the covariances of all inputs and outputs ought to be included, in particular the risk of high levels of oil burning in dry years, given the often tight construction schedules of the required hydro-stations (cf. [7]), and the cost of blackouts in case of power failure due to the total inelasticity of a smelter's power demand. The determination of these risk factors and their covariances evidently warrants a separate study.

In the long run the greatest risk, perhaps, is the expected constancy, in real terms, of the aluminium price if the electricity charge is tied to it, while the energy-determined prices of imported materials, as well as the opportunity cost of power (below) rise exponentially.

6. The Rising Marginal Cost of Electricity

The real marginal cost of electricity must rise significantly with any large-scale power addition, for at least four reasons.

First, the Samuelson-Stolper theorem: if the world price for a traded commodity rises (or, equivalently, if the commodity is subsidized) the real price of a factor which it absorbs relatively intensively, in this case energy, increases.

Second, since the LAC* curve is rising it is axiomatic that the LMC curve rises even faster (fig. 3). Efficient allocation requires that all other consumers pay the higher price ("extra payment" in fig. 3) irrespective of smelter subsidy. If the smelter is subsidized beyond, say, average cost they should pay the further amount indicated as "subsidy" in the figure. Researchers often underestimate the present value of electricity cost by charging prices a, b, c... in successive

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*LAC, SAC denote long-run, respectively short-run, average cost. Similarly, LMC, SMC refer to long-run and short-run marginal cost.
Figure 3 - LMC Electricity
periods rather than the (suitably discounted) final LMC throughout.*

The error is very significant: initial under-costing (typically at
less than 1c/unit until 1990) is decisive, while higher costs later
on matter little because at discount rates of, say, 10%, discount
factors beyond the first decade are very large.

The above argument can be obviated only in the case of hori-
Zontal cost curves. These, however, are excluded by the Hotelling
rule (below), even in the presence of a so-called backstop resource
such as lignite coal: indeed, it is not the full extraction cost
of lignite that ought to be charged but its opportunity cost, which
must rise exponentially like that of oil. The notion of expanding
hydro-power at constant LMC is simply a logical error, not an
accounting matter.**

Third, without entering into a disquisition on the complex wel-
fare calculus of peakload pricing, it is intuitively clear that rate
reductions for large baseloaders within a system of given capacity
cannot simply be extended, in general, to extra capacity for a base-
loader who needs guaranteed constant power 24 hours a day, every day
of the year, to be supplied on top of present peak demands. This
follows at once from the observation that, in equilibrium, LMC ≤ SMC.
(Since the LAC curve is an envelope of SAC curves LMC ≤ SMC would imply
suboptimal hydro-capacity.)

* Thereby ignoring the so-called producer's surplus.

** In Australia Swan [28] provides estimates of the substantial sub-
sidies involved in charging the Alcoa smelter, under construction
at Portland in SW Victoria, the average historical, instead of the
long-run marginal, cost of electricity. Dick [3] points out the
difference between the 1978-79 extraction cost of coal in New South
Wales, some $A10.30/t, charged by the electricity company, and the
opportunity cost (in this case the export parity price) of $A26/t.
The discrepancy amounts to an annual subsidy of $A60m. For a com-
parative study of hydro development in Newfoundland, Tasmania, and
the South Island see Crabb [3].
Fourth, hydro-energy is evidently to a considerable extent a substitute for depletable fossil fuels. The key result of depletion pricing, the so-called Hotelling rule, implies that the real rent of a depletable resource rises exponentially over time at the (social) rate of discount. So, therefore, will, in dynamic equilibrium, the opportunity cost of existing hydro-potential as well as the marginal value of hydro-investment. Intuitively, the rising capital costs sunk in deeper and less accessible wells, offshore exploration, and shale development imply, by substitution, a corresponding rise in the marginal value of investment in, inter alia, power dams and coal mines. The validity of the Hotelling rule can be generalized to multi-resource depletion programming [20]. I have argued elsewhere [22] that hydro-power, as distinct from hydro-energy, should be treated like a depletable resource.

An immediate corollary of the rule is that the cost of electricity should not be discounted over time because the exponential rise exactly cancels the discount. Conversely, if the price of electricity is indexed by an aluminium price that is approximately constant over time in real terms, then the index base itself should be adjusted, by the Hotelling rule, for the increase in the opportunity cost of power over time. A possible alternative is to tie the power component of the electricity price, if not to oil, at least to the OECD GDP deflator or some such index [1].

If $k$ is the cost of one unit at time $t = 0$ its opportunity cost at time $t$ equals $ke^{-rt}$ and the PDW of one unit per annum over $T$ years is

$$\int_{0}^{T} (ke^{-rt})e^{-rt} dt = kT.$$ 

Consequently, if the electricity charge $h$ were by contract to be constant (in real terms) over time then, in order to cover the opportunity cost, we would have

---

Depletion pricing of liquid fuels in Australia is discussed by Gruen and Hillman [8].
it should satisfy

\[
(6.1) \quad \int_0^T h e^{-rt} \, dt = kT
\]

so that

\[
(6.2) \quad h = \frac{rT}{1-e^{-rt}}.
\]

The cost of hydro-electricity consists of charges for hydro-energy (kWh) and hydro-power (kW). Neglecting the former, which are relatively minor for a large baseload, the Table below lists, for different values of \( r \), the current power cost \( k \) and the corresponding equivalent constant cost (or Hotelling value) \( h \) for the five Upper Clutha stations and for the ten Lower Waitaki stations in New Zealand. The Upper Clutha mid-1980 capital cost of $813m for 3,000 GWh p.a. was derived in [22]. The “early 1980” Lower Waitaki figure is $923m (about $1,230m for 4,000 GWh p.a. according to the NEPA, 14 February 1981).

<table>
<thead>
<tr>
<th>Discount Rate</th>
<th>Upper Clutha (mid-1980 $)</th>
<th>Lower Waitaki (early-1980 $)</th>
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<tr>
<td>( r )</td>
<td>( k )</td>
<td>( h )</td>
</tr>
<tr>
<td>4%</td>
<td>1.33</td>
<td>2.76</td>
</tr>
<tr>
<td>5%</td>
<td>1.54</td>
<td>3.71</td>
</tr>
<tr>
<td>6%</td>
<td>1.76</td>
<td>4.88</td>
</tr>
</tbody>
</table>

\( k \): current power cost.  
\( h \): equivalent constant cost (Hotelling value) over the 42-year smelter lifespan.

More generally, if the electricity charge is linked to the aluminium price \( p(t) \), indexed \( p(0) = 1 \), by a formula \( h = h(p(t)) \) then the left side of (6.1) takes the value \( L[h(p(t))]_0^T \) of the corresponding Laplace transform. If the charge is simply proportional to \( p(t) \) and the price trend is \( p(0)e^{rt} \) one substitutes \( r-a \) for \( r \) in (6.1), (6.2).
REFERENCES


