Where will new nuclear power plants be constructed? - Validation of a predictive model

Paul Nelson, **Christopher M. Sprecher**

<Nuclear Security Science and Policy Institute, Department of Political Science>
Texas A&M University
College Station, Texas, 77843-<3473,4348> USA
E-mail: <pnelson@ne, sprecher@politics>.tamu.edu

Abstract:

Nuclear reliance (percentage of electrical generation from nuclear) has been shown to be satisfactorily predicted by a simple linear regression on various characteristics of states. It is hypothesized that nuclear deficit := actual electrical generation by nuclear minus predicted can be used to predict the degree of intent of states to rely on nuclear generation of electricity. This hypothesis is validated against two different measures of (relatively near-term) nuclear intent, in terms of an error measure developed for this nuclear deficit performs marginally satisfactorily as a predictor, but there is room for improvement. Possible sources of improvement that are suggested by a detailed analysis of the predictive errors include incorporation of a "wealth effect" in the underlying regression, and incorporation of anticipated growth in demand for electricity in the predictions from current nuclear deficits.

Keywords: electricity, predictions, power, reactors, states, statistics,

1. Introduction

The IAEA has provided [1] estimates of an answer to the titular question, as aggregated by regions, based on a survey of various member states that have indicated an interest in hosting new nuclear power plants (NPPs). This "intent-based" methodology is certainly one important way to approach the question, but official bodies and agencies have been known to misestimate capabilities. This paper comprises an alternative empirical approach. This empirical approach is based on prior work of the authors [2] that attempts to correlate current national "nuclear reliances" (fraction of electricity generated by NPPs) with various national attributes. The hope is that this "data-based" approach could lead to a more objective complement to the intent-based methodology, perhaps particularly in estimating the course of future events for states having little prior experience with civil nuclear energy. An additional characteristic of such models is their potential for exploring consequences of changes in international norms or national policies.

In more detail, this prior work is briefly summarized in the following Section 2. In Section 3 we then apply the earlier empirical model to list the number of NPPs (suitably defined) "predicted," for each of the 86 states in the data base underlying this model, along with the corresponding differences between predicted and current actual NPPs. It is hypothesized that these differences, termed as "nuclear deficits," measure the current incentive for a state to acquire additional NPPs. In Section 4 this hypothesis is applied by comparing the nuclear deficits to two presently available more-or-less objective measures of intent: NPPs under construction and NPPs planned. A novel measure of the quality of a prediction of intents, termed as "composite error," is introduced in Section 5. The composite error is then employed in Section 6 to judge quantitatively the quality of nuclear deficit as a predictor of intent, as measured by NPPs under construction and NPPs planned. Results are summarized in the concluding Section 7.

2. Summary of the empirical model

By "nuclear reliance" is intended the fraction of the electrical energy generated within a state that comes from NPPs. The empirical model stems from stepwise (ordinary least-squares) regression, with nuclear reliance as the independent variable. The underlying database consisted of the 89 nations in the world that had, in 2006, either a population of over 20 million or a GDP of over $20 billion, less three states (Afghanistan, Puerto Rico and Uganda) for which some of the requisite data were not available. The resulting 86 "nuclear candidate" (86NC) states included all except one (Armenia) that in 2007 hosted an operating NPP.

The linear model that resulted [2] from this regression ($R^2 = 0.53$, Bulgaria, France, Lithuania, Slovenia, Switzerland and Ukraine as persistent outliers) is

$$\widehat{NR} = \underset{[8\times 10^{-11}]}{(.30 \pm .04)}IC? + \underset{[.004]}{(.097 \pm .032)}ALGN? - \underset{[6\times 10^{-4}]}{(.33 \pm .09)}COAL - \underset{[.01]}{(.13 \pm .05)}FCS? + \underset{[.015]}{(.11 \pm .04)}PLTY - .034, \quad (1)$$

where $\widehat{NR}$ is predicted nuclear reliance, the estimated predictors (coefficients of the independent variables on the right) are presented as (estimate ± standard deviation), and the independent variables on the right are as follows:

- *IC?* is a (0,1)-valued measure of national effort to commercialize indigenously developed nuclear technology and finished (not raw) materials or energy on the international market. This variable was assigned a value of one for the *de jure* nuclear-weapon states, except China, plus Argentina, Belgium, Canada, Japan, Kazakhstan, Lithuania, the Netherlands, Slovakia, South Africa, South Korea and Sweden, based on a judgment that these states have significant activities in the international market for nuclear technology, including refined materials. A value of zero was assigned to the remaining 86NC states;
- *ALGN?* is a "dummy" variable, assigned value one if neither a fuel-cycle state (below) nor a *de jure* nuclear weapon state under the NPT, but either a successor state of the former Soviet Union or at one time a member of NATO, SEATO or the Warsaw Pact. Values of one also assigned to Pakistan and Taiwan. Otherwise a value of zero is assigned. This attribute is intended as an index of the historic degree of assurance that might have been perceived by a state not in a position to meet its needs for nuclear material and technology from indigenous resources;
- *COAL* is the ratio of national coal reserves (taken from [3]) to population of the state (from [4]) as normalized through division by the maximum value, over all states in the 86NC database.
- *FCS?* has value one for the fuel-cycle states, and zero otherwise. Fuel-cycle states were taken as the *de facto* nuclear-weapon states that are not nuclear weapon states (India, Israel and Pakistan), and additionally Argentina, Brazil, Canada, Japan and the Netherlands. The remaining 86NC states are assigned the value zero.
- *PLTY* is a standard political-science attribute measuring the degree to which a state has democratic tendencies as taken from a widely-used political-science data base [5], linearly renormalized to range from zero to one.

The values in brackets in (1), below an estimated predictor value, are the *p*-statistics associated to these estimates. The various independent variables are listed in the order in which they are added to the model via continued iterations of the regression process. Because selection of independent variables was based on smallest *p*-value at time of step, this tends to correspond to order of increasing associated *p*-values; however, that is not absolutely necessary, as the *p*-statistics evolve across the various steps. For example, note the inversion of *p*-values between the *ALGN?* and *COAL* variables.

3. Predicted nuclear reliances and nuclear deficits

Table 1 consists of an alphabetized list of all states in the 86NC database (first column), the number of modern NPPs predicted from the linear model (1) in the second column, the equivalent number of actual modern NPPs (third column), and the nuclear deficits (predicted minus actual) in the fourth column. Here a “modern NPP” is defined as the annual production of electrical energy from a 1000 MWe NPP, operating at 80% capacity factor. Nuclear deficits greater than one modern NPP are highlighted in green (15 states) and those less than negative one modern NPP are highlighted in red (13 states). These putatively correspond respectively to significant deficits or surpluses of capacity for civil nuclear energy, relative to mean international practice.

Table 2 contains the same data, except now the states are listed in order of decreasing nuclear deficits.

We now investigate the extent to which nuclear deficit corresponds to two-different measures of the near-term intent of the 86NC states to build new NPPs.

4. Comparison of nuclear deficits to near-term measures of intent

Here we compare estimates of nuclear intent derived from the nuclear deficits of Tables 1 and 2 against two different readily available measures of the near-term intent of states:

- *Reactors under construction*, as reported in World Nuclear Association [6]. This reference defines “under construction” as first concrete for reactor poured, or major refurbishment under way.
- *New reactors planned* +, by which we intend reactors under construction, as above, plus reactors planned, per [6]. Here “planned” means “approvals, funding or major commitment in place, mostly expected in operation within 8 years, or construction well advanced but

Table 1: Predicted and actual civil nuclear power plants (ordered alphabetically, by state).

State	NPPs (predicted)	NPPs (actual)	Nuclear deficit
Algeria	0.0	0.0	0.0
Argentina	3.4	3.0	0.4
Australia	-5.3	0.0	-5.3
Austria	0.6	0.0	0.6
Bangladesh	0.2	0.0	0.2
Belarus	0.3	0.0	0.3
Belgium	4.4	6.2	-1.9
Brazil	-3.9	2.3	-6.2
Bulgaria	1.0	2.5	-1.5
Canada	19.8	11.3	8.4
Chile	0.5	0.0	0.5
China	-8.7	5.4	-14.1
Colombia	0.2	0.0	0.2
Congo-Kinshasa	0.0	0.0	0.0
Croatia	0.3	0.0	0.3
Cuba	0.0	0.0	0.0
Czech Republic	1.5	2.2	-0.7
Denmark	0.8	0.0	0.8
Egypt	-0.2	0.0	-0.2
Ethiopia	0.0	0.0	0.0
Finland	0.7	2.5	-1.8
France	28.8	61.3	-32.5
Germany	14.0	22.8	-8.9
Ghana	0.0	0.0	0.0
Greece	1.4	0.0	1.4
Guatemala	0.1	0.0	0.1

Hong Kong	0.1	0.0	0.1
Hungary	0.8	1.8	-1.0
India	-7.4	3.4	-10.8
Indonesia	1.0	0.0	1.0
Iran	0.6	0.0	0.6
Iraq	-0.1	0.0	-0.1
Ireland	0.2	0.0	0.2
Israel	-0.3	0.0	-0.3
Italy	6.7	0.0	6.7
Japan	35.8	32.2	3.6
Kazakhstan	0.7	0.0	0.7
Kenya	0.0	0.0	0.0
Kuwait	-0.1	0.0	-0.1
Lebanon	0.0	0.0	0.0
Libya	-0.1	0.0	-0.1
Lithuania	0.9	1.5	-0.6
Malaysia	0.4	0.0	0.4
Mexico	1.9	1.3	0.7
Morocco	0.0	0.0	0.0
Myanmar	0.0	0.0	0.0
Nepal	0.0	0.0	0.0
Netherlands	3.2	0.5	2.7
New Zealand	1.0	0.0	1.0
Nigeria	0.1	0.0	0.1
North Korea	-0.1	0.0	-0.1
Norway	3.3	0.0	3.3
Pakistan	-0.5	0.3	-0.8
Peru	0.2	0.0	0.2
Philippines	0.5	0.0	0.5
Poland	2.2	0.0	2.2
Portugal	1.1	0.0	1.1
Qatar	0.0	0.0	0.0
Romania	1.3	0.8	0.5
Russia	39.1	21.2	18.0
Saudi Arabia	-0.6	0.0	-0.6
Serbia	0.3	0.0	0.3
Singapore	0.0	0.0	0.0
Slovakia	2.0	2.5	-0.5
Slovenia	0.1	0.8	-0.6
South Africa	6.2	2.0	4.3
South Korea	24.2	21.0	3.2
Spain	6.5	10.0	-3.5
Sri Lanka	0.1	0.0	0.1
Sudan	0.0	0.0	0.0
Sweden	8.2	9.0	-0.7
Switzerland	0.6	2.9	-2.3
Syria	-0.1	0.0	-0.1
Taiwan	4.9	6.6	-1.7
Tanzania	0.0	0.0	0.0
Thailand	1.2	0.0	1.2
Tunisia	0.0	0.0	0.0
Turkey	3.4	0.0	3.4
UAE	-0.1	0.0	-0.1
UK	20.0	11.2	8.8
Ukraine	2.4	11.0	-8.6
USA	181.3	115.5	65.8
Uzbekistan	0.4	0.0	0.4
Venezuela	0.7	0.0	0.7
Vietnam	-0.1	0.0	-0.1
Yemen	0.0	0.0	0.0

Table 2: Data for civil nuclear power plants (ordered by decreasing nuclear deficit)

State	NPPs (predicted)	NPPs (actual)	Nuclear deficit
USA	181.3	115.5	65.8
Russia	39.1	21.2	18.0
UK	20.0	11.2	8.8
Canada	19.8	11.3	8.4
Italy	6.7	0.0	6.7
South Africa	6.2	2.0	4.3
Japan	35.8	32.2	3.6
Turkey	3.4	0.0	3.4
Norway	3.3	0.0	3.3
South Korea	24.2	21.0	3.2
Netherlands	3.2	0.5	2.7
Poland	2.2	0.0	2.2
Greece	1.4	0.0	1.4
Thailand	1.2	0.0	1.2
Portugal	1.1	0.0	1.1
New Zealand	1.0	0.0	1.0
Indonesia	1.0	0.0	1.0
Denmark	0.8	0.0	0.8
Kazakhstan	0.7	0.0	0.7
Venezuela	0.7	0.0	0.7
Mexico	1.9	1.3	0.7
Austria	0.6	0.0	0.6
Iran	0.6	0.0	0.6
Romania	1.3	0.8	0.5
Philippines	0.5	0.0	0.5
Chile	0.5	0.0	0.5
Malaysia	0.4	0.0	0.4
Uzbekistan	0.4	0.0	0.4
Argentina	3.4	3.0	0.4
Belarus	0.3	0.0	0.3
Serbia	0.3	0.0	0.3
Croatia	0.3	0.0	0.3
Ireland	0.2	0.0	0.2
Colombia	0.2	0.0	0.2
Peru	0.2	0.0	0.2
Bangladesh	0.2	0.0	0.2
Nigeria	0.1	0.0	0.1
Hong Kong	0.1	0.0	0.1
Guatemala	0.1	0.0	0.1
Sri Lanka	0.1	0.0	0.1
Ghana	0.0	0.0	0.0
Kenya	0.0	0.0	0.0
Singapore	0.0	0.0	0.0
Congo-Kinshasa	0.0	0.0	0.0
Algeria	0.0	0.0	0.0
Ethiopia	0.0	0.0	0.0
Tanzania	0.0	0.0	0.0
Yemen	0.0	0.0	0.0
Nepal	0.0	0.0	0.0
Tunisia	0.0	0.0	0.0
Sudan	0.0	0.0	0.0
Lebanon	0.0	0.0	0.0
Myanmar	0.0	0.0	0.0
Cuba	0.0	0.0	0.0
Morocco	0.0	0.0	0.0
Qatar	0.0	0.0	0.0
Libya	-0.1	0.0	-0.1
Syria	-0.1	0.0	-0.1
Kuwait	-0.1	0.0	-0.1
North Korea	-0.1	0.0	-0.1

Iraq	-0.1	0.0	-0.1
UAE	-0.1	0.0	-0.1
Vietnam	-0.1	0.0	-0.1
Egypt	-0.2	0.0	-0.2
Israel	-0.3	0.0	-0.3
Slovakia	2.0	2.5	-0.5
Saudi Arabia	-0.6	0.0	-0.6
Slovenia	0.1	0.8	-0.6
Lithuania	0.9	1.5	-0.6
Czech Republic	1.5	2.2	-0.7
Sweden	8.2	9.0	-0.7
Pakistan	-0.5	0.3	-0.8
Hungary	0.8	1.8	-1.0
Bulgaria	1.0	2.5	-1.5
Taiwan	4.9	6.6	-1.7
Finland	0.7	2.5	-1.8
Belgium	4.4	6.2	-1.9
Switzerland	0.6	2.9	-2.3
Spain	6.5	10.0	-3.5
Australia	-5.3	0.0	-5.3
Brazil	-3.9	2.3	-6.2
Ukraine	2.4	11.0	-8.6
Germany	14.0	22.8	-8.9
India	-7.4	3.4	-10.8
China	-8.7	5.4	-14.1
France	28.8	61.3	-32.5

suspended indefinitely." Except as expressly noted otherwise, data for "reactors planned" are taken from [6].

Table 3 lists, in alphabetical order by state, the 86NC states, their respective nuclear deficits, and these two measures of near-term nuclear intent. Absence of data in the indicated sources was represented as value zero.

For some states (e.g., Algeria, Canada) the nuclear deficit seems to be an acceptable estimate of one or both of these measures of near-term nuclear intent. For other states (e.g., China, India) it appears to be a very poor predictor of either of these measures of intent. This raises the question of how to judge the quality of a predictor of any measure of nuclear intent.

We answer that question in the following Section 5, by introducing a novel error measure, termed as "composite error," that is suggested to provide such a measure of the quality of a predictor of nuclear intent, both for individual states and for ensembles in totality. This measure is then employed, in Section 6, to analysis the quality of nuclear deficit as a predictor of nuclear intent, first in aggregate over the entire ensemble consisting of the 86NC states, then for individual states. Some of the possible reasons for poor performance of nuclear deficit as a predictor for individual states are discussed in the concluding Section 7.

5. Composite error: theory

For any state (i) and measure of nuclear intent, say $NI_{i,}$ we define the "composite error" of some estimate of nuclear intent, say $E\,NI_{i,}$ as

$$CE_i = \frac{ENI_i - NI_i}{\max\{1.0, |ENI_i|, |NI_i|, |ENI_i - NI_i|\}}. \qquad (2)$$

Composite errors thus defined necessarily lie between -1 and 1, with the extremes corresponding to the nuclear deficit severely respectively underestimating or overestimating the particular measure of

Table 3: Nuclear deficits, for the 86NC states, with the two near-term measures of nuclear intent (ordered alphabetically, by state).

State	Nuclear deficit	Reactors under construction	New reactors planned +
Algeria	0.0	0	0
Argentina	0.4	0.7	1.4
Australia	-5.3	0	0
Austria	0.6	0	0
Bangladesh	0.2	0	0
Belarus	0.3	0	0
Belgium	-1.9	0	0
Brazil	-6.2	0	1.2
Bulgaria	-1.5	0	1.9
Canada	8.4	1.5	4.8
Chile	0.5	0	0
China	-14.1	8.7	33.6
Colombia	0.2	0	0
Congo-Kinshasa	0.0	0	0
Croatia	0.3	0	0
Cuba	0.0	0	0
Czech Republic	-0.7	0	0
Denmark	0.8	0	0
Egypt	-0.2	0	1
Ethiopia	0.0	0	0
Finland	-1.8	1.6	1.6
France	-32.5	1.6	1.6
Germany	-8.9	0	0
Ghana	0.0	0	0
Greece	1.4	0	0
Guatemala	0.1	0	0
Hong Kong	0.1	0	0
Hungary	-1.0	0	0
India	-10.8	3	12.8
Indonesia	1.0	0	2
Iran	0.6	0.9	2.8
Iraq	-0.1	0	0
Ireland	0.2	0	0
Israel	-0.3	0	0
Italy	6.7	0	0
Japan	3.6	2.3	17.3
Kazakhstan	0.7	0	0.6
Kenya	0.0	0	0
Kuwait	-0.1	0	0
Lebanon	0.0	0	0
Libya	-0.1	0	0
Lithuania	-0.6	0	0
Malaysia	0.4	0	0
Mexico	0.7	0	0
Morocco	0.0	0	0
Myanmar	0.0	0	0
Nepal	0.0	0	0
Netherlands	2.7	0	0
New Zealand	1.0	0	0
Nigeria	0.1	0	0
North Korea	-0.1	0	1
Norway	3.3	0	0
Pakistan	-0.8	0.3	0.9
Peru	0.2	0	0
Philippines	0.5	0	0
Poland	2.2	0	0
Portugal	1.1	0	0
Qatar	0.0	0	0

Romania	0.5	0	1.3
Russia	18.0	6	18.9
Saudi Arabia	-0.6	0	0
Serbia	0.3	0	0
Singapore	0.0	0	0
Slovakia	-0.5	0.8	0.8
Slovenia	-0.6	0	0
South Africa	4.3	0	3.6
South Korea	3.2	3	9.4
Spain	-3.5	0	0
Sri Lanka	0.1	0	0
Sudan	0.0	0	0
Sweden	-0.7	0	0
Switzerland	-2.3	0	0
Syria	-0.1	0	0
Taiwan	-1.7	0	0
Tanzania	0.0	0	0
Thailand	1.2	0	2
Tunisia	0.0	0	0
Turkey	3.4	0	2.4
UAE	-0.1	0	4.5
UK	8.8	0	0
Ukraine	-8.6	0	1.9
USA	65.8	0	15
Uzbekistan	0.4	0	0
Venezuela	0.7	0	0
Vietnam	-0.1	0	2
Yemen	0.0	0	0

nuclear intent. Composite errors less in magnitude than about .5 may be considered acceptable, as they represent errors that are, on (root-mean-square) average, smaller than the least restrictive of a factor of two in number of modern NPPs, or half of a modern NPP.

For an aggregate error measure we employ the composite-root-mean-square error,

$$CRMSE = \sqrt{\frac{1}{n}\sum_{i=1}^{n} CE_i^2}\,.$$

Similarly values of the composite-root-mean-square error less than about .5 are acceptable, and values near one are most unacceptable. Alternately we could employ the composite R^2 value

$$\text{comp } R^2 = 1 - CRMSE^2,$$

as an aggregate measure of goodness of fit (of the nuclear deficits to the subject measure of nuclear intent). From the preceding, values of ~ .75 are quite acceptable for the composite R^2, while values near zero are very undesirable.

As an estimate of the various measures of nuclear intent we employ here the adjusted nuclear deficit := max{0, nuclear deficit}. This is appropriate because the WNA data employed here do not take into account projected decommissioning of NPPs, so that negative values of the various measures of intent are impossible. A viable alternative, not pursued here, would be to adjust the measures of intent for those states that have made (or had externally imposed) commitments to phase out nuclear power (e.g., Germany, Lithuania, Spain, Sweden), and use nuclear deficit adjusted as max{nuclear deficit, -existing NPPs}.

6. Composite error: application

Table 4 displays the adjusted nuclear deficits, the individual composite errors, the aggregate composite R-squares, the aggregate composite root-mean-square errors and the composite R^2 for the adjusted nuclear deficits as a fit to the two near-term measures of nuclear intent previously shown in Table 3.

On the basis of the composite R^2 values (or the composite root-mean-square errors), the adjusted nuclear deficits seem to give an aggregate fit to the two measures of near-term intent that are close to acceptable Further, the fit to "reactors under construction" seems slightly better than that to "reactors planned+." However, even for "reactors under construction" the composite error reaches the maximum possible magnitude of unity for nearly one-fifth of the states considered (seventeen of the eighty six), which highlights that the fit is at best marginally acceptable.

In order better to understand the nature of this deficiency, it is useful to study more closely the distributions of the composite errors for adjusted nuclear deficit as an estimate of the two measures of nuclear intent. In Figures 1 and 2 below we approach that by displaying the composite errors in a histogram, with five equally spaced bins. These are labelled as follows: "severely underestimated" (-1.0 ≤ composite error < -0.6), "slightly underestimated" (-0.6 ≤ composite error < -0.2), "well estimated" (-0.2 ≤ composite error < 0.2), "slightly overestimated" (0.2 ≤ composite error < 0.6) and "severely overestimated" (0.6 ≤ composite error ≤ 1.0)

Figure 1 shows that the nearly acceptable value (0.73) of composite R^2 for "reactors under construction" as a measure of nuclear intent is attained via approximately half of the composite errors being well estimated. Of the reactors under construction not well estimated, substantially more are overestimated than are underestimated; i.e., more states are "nuclearly timid" than warranted by their adjusted nuclear deficits. Further, of those overestimated, approximately two-thirds are severely overestimated. That is, most of the nuclearly timid states are severely nuclearly timid.

If "reactors planned +" is used as the measure of intent, rather than reactors under construction, then in some aggregate sense there there is a greater nuclear intent. One might therefore expect something of a uniform shift to the left of the distribution shown in Figure 1, with the possibility of an improved (increased) value of R^2. The corresponding (slightly) smaller value (0.68) of R^2 in Table 4 shows this expectation is not met. The mechanism underlying this is perhaps best exposed through a bin-by-bin comparison of the histogram in Figure 2 to that of Figure 1. In Figure 2 slightly fewer states seem have severely overestimated nuclear intent, and about the same are slightly overestimated, which collectively in itself should result in a slightly improved composite error. However, slightly fewer have a well-estimated nuclear intent, about the same have slightly underestimated nuclear intent, and substantially more are significantly overestimated. On balance, there seems to be a net transfer from the substantially overestimated and well-estimated bins to the substantially underestimnated bin. That is, for "reactors planned +" as a measure of nuclear intent, significantly more states display a nuclearly aggressive stance than would be warranted by their current nuclear deficit.

For purposes of developing approaches (e.g.,additional independent variables) that further improve the predictive model, it potentially is useful to pinpoint the states for which the composite errors are largest in magnitude. Table 5 lists, in order of decreasing composite error, the individual states (from the 86NC database) for which the nuclear deficit severely underestimates (composite error ≤ -0.7, to one digit of accuracy) or severely overestimates (composite error ≥ 0.6, to a single digit) "reactors planned +."

Table 5 shows that the nuclearly timid states (composite error ≥ 0.6) consist almost entirely, the sole exception being the US, of states having no reactors planned or under construction. But four of these states (Italy, Mexico, UK and Poland) have proposed new NPPs, as the US has proposed more than the 15 shown as "planned+." Nonetheless, these proposed plants do not meet the rather stringent criterion used here for a plant to be considered "planned." The remaining eight (of 13) nuclearly timid states consist of states that fit the pattern of relatively developed states having little or no existing nuclear power generation, a rather small nuclear deficit (order of one or two), and no known serious proposals to construct nuclear plants. This observation suggests the possibility of some type of

Table 4: Composite errors, for nuclear deficits as a fit to the two near-term measures of nuclear intent, the 86NC states, and in aggregate.

State	Adjusted nuclear deficits	Composite error for reactors under construction	Composite error for reactors planned +
Algeria	0.0	0.0	0.0
Argentina	0.4	-0.3	-0.8
Australia	0.0	0.0	0.0
Austria	0.6	0.6	0.6
Bangladesh	0.2	0.2	0.2
Belarus	0.3	0.3	0.3
Belgium	0.0	0.0	0.0
Brazil	0.0	0.0	-1.0
Bulgaria	0.0	0.0	-1.0
Canada	8.4	0.8	0.4
Chile	0.5	0.5	0.5
China	0.0	-1.0	-1.0
Colombia	0.2	0.2	0.2
Congo-Kinshasa	0.0	0.0	0.0
Croatia	0.3	0.3	0.3
Cuba	0.0	0.0	0.0
Czech Republic	0.0	0.0	0.0
Denmark	0.8	0.8	0.8
Egypt	0.0	0.0	-1.0
Ethiopia	0.0	0.0	0.0
Finland	0.0	-1.0	-1.0
France	0.0	-1.0	-1.0
Germany	0.0	0.0	0.0
Ghana	0.0	0.0	0.0
Greece	1.4	1.0	1.0
Guatemala	0.1	0.1	0.1
Hong Kong	0.1	0.1	0.1
Hungary	0.0	0.0	0.0
India	0.0	-1.0	-1.0
Indonesia	1.0	1.0	-0.5
Iran	0.6	-0.3	-0.8
Iraq	0.0	0.0	0.0
Ireland	0.2	0.2	0.2
Israel	0.0	0.0	0.0
Italy	6.7	1.0	1.0
Japan	3.6	0.4	-0.8
Kazakhstan	0.7	0.7	0.1
Kenya	0.0	0.0	0.0
Kuwait	0.0	0.0	0.0
Lebanon	0.0	0.0	0.0
Libya	0.0	0.0	0.0
Lithuania	0.0	0.0	0.0
Malaysia	0.4	0.4	0.4
Mexico	0.7	0.7	0.7
Morocco	0.0	0.0	0.0
Myanmar	0.0	0.0	0.0
Nepal	0.0	0.0	0.0
Netherlands	2.7	1.0	1.0
New Zealand	1.0	1.0	1.0
Nigeria	0.1	0.1	0.1
North Korea	0.0	0.0	-1.0
Norway	3.3	1.0	1.0
Pakistan	0.0	-0.3	-0.9
Peru	0.2	0.2	0.2
Philippines	0.5	0.5	0.5
Poland	2.2	1.0	1.0
Portugal	1.1	1.0	1.0

Qatar	0.0	0.0	0.0
Romania	0.5	0.5	-0.6
Russia	18.0	0.7	-0.1
Saudi Arabia	0.0	0.0	0.0
Serbia	0.3	0.3	0.3
Singapore	0.0	0.0	0.0
Slovakia	0.0	-0.8	-0.8
Slovenia	0.0	0.0	0.0
South Africa	4.3	1.0	0.2
South Korea	3.2	0.1	-0.7
Spain	0.0	0.0	0.0
Sri Lanka	0.1	0.1	0.1
Sudan	0.0	0.0	0.0
Sweden	0.0	0.0	0.0
Switzerland	0.0	0.0	0.0
Syria	0.0	0.0	0.0
Taiwan	0.0	0.0	0.0
Tanzania	0.0	0.0	0.0
Thailand	1.2	1.0	-0.4
Tunisia	0.0	0.0	0.0
Turkey	3.4	1.0	0.3
UAE	0.0	0.0	-1.0
UK	8.8	1.0	1.0
Ukraine	0.0	0.0	-1.0
USA	65.8	1.0	0.8
Uzbekistan	0.4	0.4	0.4
Venezuela	0.7	0.7	0.7
Vietnam	0.0	0.0	-1.0
Yemen	0.0	0.0	0.0
CRMSE	-	0.52	0.57
comp R^2	-	0.73	0.68

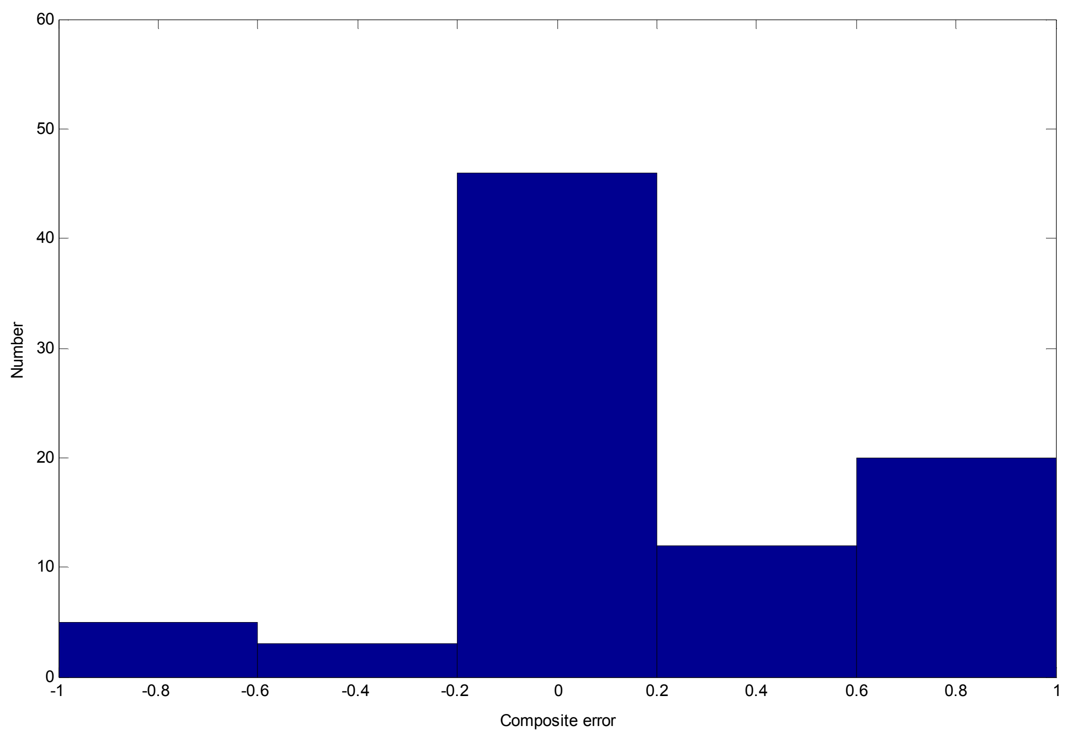

Figure 1 - Distribution of composite errors, for adjusted nuclear deficits as an estimate of reactors under construction

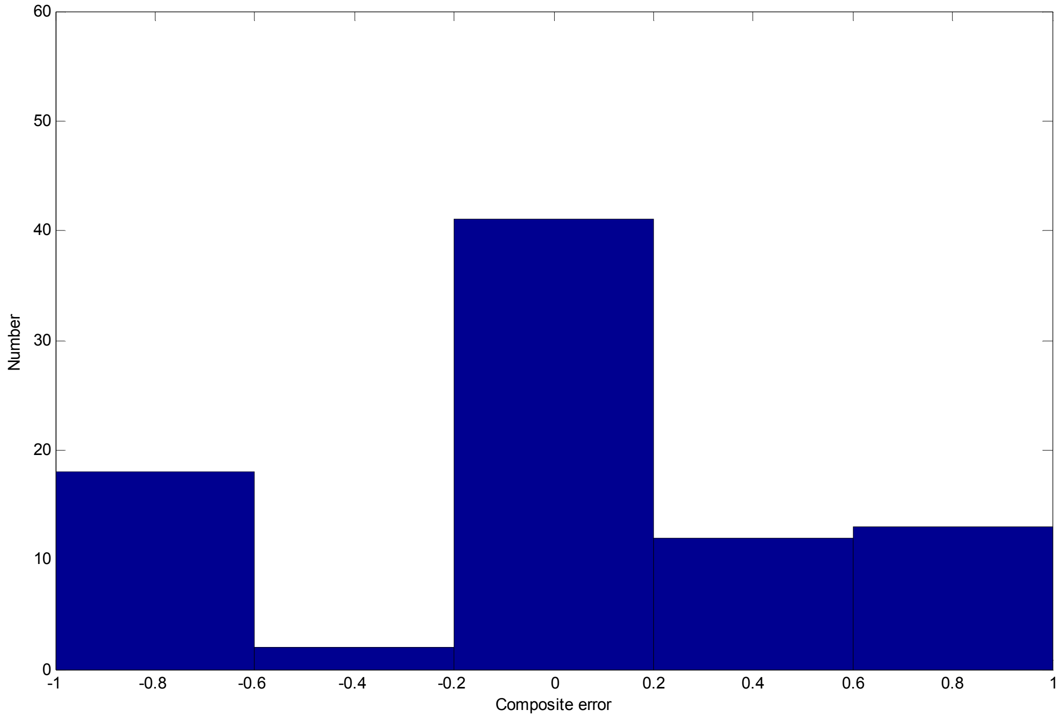

Figure 2 - Distribution of composite errors, for adjusted nuclear deficits as an estimate of reactors planned +

"wealth effect," which is to say a phenomenon under which states sufficiently wealthy choose to use some of that wealth to avoid choosing civil nuclear power.

The nuclearly aggressive states (composite error < -0.6, to one digit of accuracy) present a more complex picture. Eleven of these 17 states arguably have significant existing civil nuclear programs. A resonable conjecture is that nuclear deficit underestimates the near-term nuclear intent of these states because that intent takes into account near-term projections of their growth in electricity demand, which is not taken into account in the (current version of) the estimate provided by nuclear deficits. The remaining six nuclearly aggressive states (Egypt, Iran, North Korea, Pakistan, the UAE and Vietnam) all have relatively little experience with civil nuclear power plants. It will be interesting to see whether they succeed in finding ways to overcome this lack of experience that suffice to establish a viable civil nuclear program in the near term (next ten years).

7. Conclusion

The linear regression model developed earlier by the authors [2] has been validated as a predictor of states' intent to develop civil nuclear power. This validation was affected against two different measures of near-term nuclear intent: "reactors under construction" and "reactors planned + under construction," where the term "planned" is employed as by the World Nuclear Association [6]. A "composite error" was developed as a measure of the aggregate and individual adequacy of predictors of nuclear intent. In terms of this error measure, the "nuclear deficit" of a state (difference between nuclear reliance predicted by the regression model and actual nuclear reliance = percentage of electricity generated by nuclear plants) was shown to provide a marginally satisfactory prediction of plants under construction, and a nearly satisfactory prediction of the slightly longer term measure of intent provided by "reactors planned +."

Table 5: States for which nuclear deficit severely misestimates reactors planned +, in order of decreasing composite error relative to reactors planned +.

State	Adjusted nuclear deficits	NPPs (actual)	Reactors planned +	Composite error for reactors planned +
Greece	1.4	0.0	0	1.0
Italy	6.7	0.0	0	1.0
Netherlands	2.7	0.5	0	1.0
Norway	3.3	0.0	0	1.0
Poland	2.2	0.0	0	1.0
Portugal	1.1	0.0	0	1.0
UK	8.8	11.2	0	1.0
New Zealand	1.0	0.0	0	1.0
Denmark	0.8	0.0	0	0.8
USA	65.8	115.5	15	0.8
Venezuela	0.7	0.0	0	0.7
Mexico	0.7	1.3	0	0.7
Austria	0.6	0.0	0.6	0.6
South Korea	3.2	21.0	9.4	-0.7
Argentina	0.4	3.0	1.4	-0.8
Japan	3.6	32.2	17.3	-0.8
Slovakia	0.0	2.5	0.8	-0.8
Iran	0.6	0.0	2.8	-0.8
Pakistan	0.0	0.3	0.9	-0.9
Brazil	0.0	2.3	1.2	-1.0
Bulgaria	0.0	2.5	1.9	-1.0
China	0.0	5.4	33.6	-1.0
Egypt	0.0	0.0	1	-1.0
Finland	0.0	2.5	1.6	-1.0
France	0.0	61.3	1.6	-1.0
India	0.0	3.4	12.8	-1.0
North Korea	0.0	0.0	1	-1.0
UAE (consortium)	0.0	0.0	4.5	-1.0
Ukraine	0.0	11.2	1.9	-1.0
Vietnam	0.0	0.0	2	-1.0

Toward further improvement of predictive capability, especially for even longer term measures of nuclear intent, the following properties of the composite errors are noted. As validated against reactors under construction, the predominant source of error stems from the fact that nuclear deficit significantly overestimates, in a number of states (20 of 86; cf. Figure 1), the number of reactors presently under construction. A detailed analysis of the states for which this significant overestimation occurs indicates (data not shown in text) the corresponding states fall into one of two patterns: 12 of the 20[a] have significant activity to further develop civil nuclear power at some stage, but essentially no plants presently under construction; the remaining eight states[b] predominantly are states having little or no existing nuclear power generation, a rather small nuclear deficit (order of one or two), and no known serious proposals to construct nuclear plants. The former group suggests the hypothesis that nuclear deficit would be better suited to predict some longer-term measure of nuclear intent. The latter pattern raises the hypothesis that some "wealth effect" exists in making the choice to "go nuclear," which is to say that some relatively wealthy states choose to exercise a portion of that wealth to avoid generation of nuclear power.

The first of these hypotheses is to some extent confirmed by the validation of nuclear deficit as a predictor of reactors planned + under construction. That is, now significantly few states (13) have this measure of intent significantly overestimated by nuclear deficit. Further, only five fit the pattern of

[a] These 12 are Canada, Indonesia, Italy, Kazakhstan, Mexico, Poland, Russia, South Africa, Thailand, Turkey, UK and USA.
[b] Austria, Denmark, Greece, Netherlands, New Zealand, Norway, Portugal and Venezuela

substantial nuclear activity in the longer term; however, there remain eight that follow the hypothesized "wealth effect" pattern.

On the other hand, in aggregate nuclear deficit is a slightly poorer predictor for this somewhat longer term measure, in that it severely underestimates it for 17 states (cf. Table 5). Eleven of these 17 have significant existing nuclear programs. We hypothesize that nuclear deficit would better predict the intent of these states if it incorporated some measure of their anticipated growth in the demand for electricity. The remaining six states possibly face significant challenges in realizing their plans to establish a significant civil nuclear program.

Finally, we also hypothesize that nuclear deficit would provide a better estimate of longer-term measures of nuclear intent if the underling linear model (1), for nuclear reliance, were adjusted to account for either the apparently increased willingness of the advanced nuclear states to meet their obligation under Article IV of the NPT, or the increasing concern about climate change. These matters are deferred to future work.

8. References

1. International Atomic Energy Agency; *Energy, Electricity and Nuclear Power Estimates for the Period up to 2030*, Reference Data Series No. 1; 2007.
2. Nelson P. and Sprecher C.M.; *What Determines the Extent of National Reliance on Civil Nuclear Power?*; Report No. NSSPI-08-014, Nuclear Security Science and Policy Institute, Texas A&M University, October 24, 2008; accessed December 25, 2008. An abbreviated version of this work has been accepted for publication in the journal *Atoms for Peace.*
3. Energy Information Administration, *World Estimated Recoverable Coal*," 2008, Table 8.2, <http://www.eia.doe.gov/fuelcoal.html> → International data → Coal → Reserves, accessed June 18, 2008.
4. Economist Newspaper Ltd.; *Pocket World in Figures*; Profile Books Ltd; London; 2007.
5. *Polity IVe database*; http://www.cidcm.umd.edu/polity/), accessed January 17, 2008. Values used for polity were specifically the "polity2" variable from the 2002 data.
6. World Nuclear Association; *World Nuclear Power Reactors 2007-08 and Uranium Requirements*; December 1, 2008; http://www.world-nuclear.org/info/reactors.html; accessed December 25, 2008.