CROSS-LEVEL INFERENCE IN POLITICAL SCIENCE

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Abstract. Political Science research encounters inferences across levels of analysis; however, they are fraught with challenges. After introducing voting examples of aggregation bias, problems posed by aggregation bias are summarized more generally. Subsequently, the article reviews the major methodological approaches to overcome aggregation bias and to solve the ecological inference (disaggregation) problem. The article highlights the possibility that aggregation bias *may* lead governments to accept (or reject) international climate agreements when negotiating as blocs of countries as compared to the distribution of the preferences of all countries involved in the negotiations.

Keywords: cross-level inference, political science, aggregation bias, ecological fallacy.

> [T]here may or not may be a unanimously preferred outcome. And even if one of the outcomes is unanimously chosen, we cannot infer that it is preferred from the fact that is universally chosen.
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> (Schelling 1978, 98-99)

1. The Problem of Cross-Level Inference

Schelling's observation points to the problem of incongruity between individual preferences and collective outcomes and the challenge to make inferences from one level of analysis about another level. Fortunately, social scientists have a long tradition in modeling across various levels of analysis or levels of aggregation. While economists often distinguish microeconomics (e.g., the study of individual firms, individual consumers, etc.) and macroeconomics (e.g., whole economies as part of the world economy), sociologists distinguish, inter alia, individuals, groups, and states. Similarly, political scientists, especially specialists in international relations, focus on at least three levels of analysis such as the individual decision-maker, country aggregates (e.g., country positions in international environmental negotiations), and the international system of countries (e.g., the occurrence of international war on the global level) (see Singer 1969; Waltz 1959; Waltz 1979). However, the problems encountered by making inferences *across* various levels of analysis do not necessarily receive adequate attention, in particular the question of whether findings at lower levels of aggregation hold or do *not* hold at a higher level of aggregation (see, e.g., Ahn et al. 1998). The electoral examples shown further below illustrate that electoral rules have a major effect on how votes are transformed into government majorities. Given the degree of possible distortion by aggregation bias (see below), it is not inconceivable by way of analogy that electoral majorities in countries on particular climate change proposals may lead governments to globally (dis)agree on international policies while the underlying populations prefer otherwise.

Furthermore, researchers are often interested in micro-level relationships but only have aggregate data at hand. The problem of cross-level inference deals with both types of problems: relating findings at lower levels of aggregation to higher levels of analysis and suggesting ways to recover individual-level relationships when only aggregate-level data are available.

A considerable part of the social science literature seems to be influenced by the research findings of William Robinson in 1950.[1]

> Robinson noted that aggregate statistical findings would not necessarily mirror the individual-level relationships underlying them. In his best-known example, he showed that states with more foreign-born residents tended to have more residents literate in English. A scholar using only aggregate data would have concluded that the foreign-born were unusually literate in English. However, the individual-level census data showed just the reverse was true: foreign-born residents were less literate in English than native-born Americans. Thus even the sign of the aggregate-level relationship was wrong. Robinson concluded that we should avoid using aggregate-level correlations to draw conclusions about otherwise unobservable individual-level relationships; he called this the "fallacy of ecological correlation." Later scholars have ameliorated Robinson’s pessimistic conclusion slightly, but never to a full degree of satisfaction (Achen and Shively 1995, 3).

Since data from both levels of analysis are available, the paradox could fortunately be resolved: The ecological fallacy occurs because particularly large groups of foreign-born persons were clustering in the same geographical grids with *highly* literate groups of persons, and while the individual-level relationship between being foreign-born and literacy is negative, the clustering of foreign-born groups with highly literate persons in cities resulted in an positive *aggregate*-level relationship. However, detection of the error in inference rests on the additional information available from individual level data - which do not

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[1] See also the reviews in Bartels and Brady (1993, 128-130) and Huckfeldt and Sprague (1993, 285-286).

always exist. More generally, patterns observed at one level of analysis are influenced by processes occurring one level “higher up” as well as one level “further below” the level of inquiry.

The latter conclusion will be illustrated by examples of aggregation problems commonly found in electoral studies (Section 2). Subsequently, I will briefly summarize the major approaches to solve the ecological inference problem in Political Science (disaggregation) (Section 3) before turning to the conclusions (Section 4).

2. Aggregation Bias

The working of aggregation bias will be introduced by way of two examples. The first example uses a general system of reasoning for individual level units and relates them to aggregate outcomes, and the second example uses election results from the 1997 British and French Parliamentary Elections to show how electoral laws lead to deviations from proportional representation.

In the first example, a reasoning system originally developed by Stützel may provide an intuitively useful scheme for analyzing the underlying dynamics between individual choice and aggregate outcomes. Using a three-step procedure, Grass and Stützel (1983) point to

(1) the effects of the behavior of individual units ("what happens if one person [country] ..."),
(2) the effects for a unit which changes its behavior earlier than others ("lead" and "lag effects"), and, finally,
(3) the collective consequences if all persons [countries] undertake the action (in comparison to the status quo ante) (Grass and Stützel 1983) (translation by the author).

For demonstration purposes, we assume that persons are sitting in an auditorium observing a fascinating presentation. As persons sit in rows on a flat (horizontal) surface, those sitting in the front rows have a natural advantage in following the presenter. Each person in the second row and beyond may improve his or her vision of the presenter (and the material presented) by standing up (Step 1). In addition, those who are standing up earlier as compared to others have an advantage in improving their vision (Step 2); however, as everyone is standing up, nobody can improve his or her vision as compared to the situation when all remain sitting (Step 3). In fact, as most persons prefer to sit rather than stand, step 3 creates the additional burden of standing as compared to sitting with the same degree of impairment of visibility.[2]

A broad range of applications have taken their point of departure from analogies of this reasoning system. The most cited example stems from Garrett Hardin's "tragedy of the commons" (Hardin 1968) where traditional herdsman utilize the common grounds for pasture in a community to maximize their own income.[3] Based on a set of strict assumptions (ibid., 4-6), Hardin deduces that the commons will be overgrazed and ultimately destroyed by the group of all herdsmen. He also extends this reasoning system to population growth and pollution problems (Hardin 1968) and advocates mutually agreed upon coercion (e.g., by way of a tax system which avoids free-riding) to avoid the unfortunate outcome to the open-access common. A myriad of studies has taken issue with these conclusions by demonstrating that at least on smaller scales, common property resource management is not necessarily doomed to lead to tragic outcomes (e.g., Ahn et al. 1998; Ostrom et al. 1994).[4] However, some authors doubt whether findings from sub-national levels of aggregation are transferable to international society (e.g., Young 1995, 33).

As opposed to such adverse outcomes, the same paradoxa may apply in a beneficial way. For example, each firm has an incentive to undercut its competitors in terms of sales price to gain additional market share (resulting, e.g., from a firms' less expensive production technology) (Grass and Stützel 1983). As more and more firms use this new technology and reduce prices (as opposed to those operating with the more expensive technology), they are still able to expand sales and market share. However, as all companies adopt the new technology, the market price in general will shrink as compared to the situation when all companies used the old technology, total sales may increase or not (depending on the specific shapes of the demand and supply curves), but consumers are certainly better served by the lower price level resulting from technological improvements and competition among firms.

Both examples show that individual level dynamics, by way of interaction or emulation, may lead to (un)wanted aggregate outcomes (vision remains impaired for most despite standing up, consumer prices decrease as production technology advances).

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[2] Persons standing in row 2 may pose an exception if persons in row 1 remain sitting. However, this does not change the overall picture for persons in rows 3 and higher.

[3] For analogies to Hardin's analysis, see also Schelling (1978, 110-115).

[4] The differences in conclusion largely relate to model specification, in particular the introduction of omitted variables (e.g., introduction of monitoring and sanctioning systems as well as limiting access to increase the probability of compliance with commonly agreed upon rules; see Ahn et al. (1998, 62-63) and Ostrom et al. (1994, chs. 2-3)).

Examples drawn from the analysis of elections illustrates a second avenue towards aggregation bias. For reasons of simplicity, we assume that elections are free in terms of competition among parties, the electorate is properly defined, and an election law exists which stipulates how (valid) votes are translated into seats in Parliament. Students of comparative politics have been advancing the various merits of different election schemes, e.g., majority rule vs. proportional representation for allocating Parliamentary seats, as well as single vs. multiple member districts (see, e.g., Lijphart 1994). Electoral laws not only influence how individual preferences translate into representation (seats in Parliament), but they are also designed to facilitate the creation of government majorities. It should be noted that many electoral systems favor large parties over smaller parties (Lijphart 1994, ch. 3). The two empirical examples to follow demonstrate the aggregation bias introduced by majority electoral laws as compared to proportional representation.

The British and French National Parliamentary elections of 1997 were held on the basis of single-member districts, i.e., the candidate receiving the relative majority or plurality of votes will represent his or her voting district in the Lower House (House of Commons in the U.K., Assemblée Nationale in France). Whereas the British undertake general elections on a single date, the French afford a two-step electoral process: In the first round, only candidates receiving an absolute majority (i.e., more than 50% of the valid votes in a voting district) will receive seats. If seats are not allocated in the first round - and only a few are - then candidates who have commanded at least 12.5% of the votes in the first round are eligible to enter the second round one week later. The outcome of the second stage is determined on the basis of which candidate commands a plurality of the votes. Results for the national elections can be found below for the British Parliamentary Election on 01 May 1997 (Table I) and the second round of the French elections to the Assemblée Nationale[5] on 01 June 1997 (Table II).[6]

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[5] In the first round of the French Parliamentary elections, only 12 seats were allocated. For reasons of exposition, results from the first round are omitted.

[6] I am grateful to Wolfgang Rüdig for providing me with authoritative results for both elections.

Table I

British Parliamentary Election, 01 May 1997

	Party	% Votes	% Seats	% Points Bias[1]
Government Party	Labor Party	45	67	+22
Opposition Parties	Conservative Party (Tories)	31	26	-5
	Liberal Democrats	17	3	-14
	Other	7	5	-2
Total		100	100	0
% Government		45	67	+22
% Opposition		55	33	-22

Data Source: http://www.bbc.co.uk/election97/live/index.htm

Notes: Figures may not add up due to rounding.
[1] The degree of bias by the electoral system ("% points bias") is computed as the difference of "% votes" and "% seats".

Table II

French Parliamentary Election, Second Round, 01 June 1997 (Mainland and Overseas)

	Party	% Valid Votes	% Seats	% Points Bias[1]
Government Parties (Coalition)	Socialists & PRS	39	44	+5
	Communists	4	6	+3
	Ecologists	2	1	0
	other left parties	4	5	+1
Opposition Parties	RPR	24	23	0
	UDF	21	19	-2
	other rightist parties	1	1	0
	National Front	6	0	-6
Total		100	100	0
% Government		48	56	+8
% Opposition		52	44	-8

Data Source: Le Monde Législatives 1997, 42; omits results from first round allocation of 12 seats.

Notes: Figures may not add up due to rounding.
[1] The degree of bias by the electoral system ("% points bias") is computed as the difference of "% valid votes" and "% seats".

Both tables contrast the percentage of seats received in Parliament with those based on an extremely simple form of proportional representation. A range of rules have been devised to allocate seats in electoral systems with proportional representation.[7] Depending on the specific rules of allocating seats under proportional representation, large or small parties are favored (Cox and Shugart 1991, 350; Lijphart 1994, ch. 2). For reasons of exposition, proportional representation was interpreted here as the perfect translation of vote shares into shares of Parliamentary seats. In our example, the British Labour party received two-thirds of the seats in Parliament with 45% of the popular vote, whereas the coalition led by the French Socialist Party received 56% of the seats (in the second round) with only 48% of electoral support. In order to easily detect the degree of bias (in percentage points), Tables I and II compute the absolute difference between the percentage of seats expected by way of proportional representation as opposed to the percentage of seats allocated by way of the respective electoral systems. In both countries, the results show that the governing party/ies have benefited substantially from the single member, relative majority electoral system as opposed to proportional representation laws.[8] In particular, the British results show a much stronger bias as compared to the French results. Moreover, *if* these countries had embraced proportional representation laws with allocation rules as used in this article, it remains conceivable that the current opposition parties would have been in power as opposed to the present government parties - or the latter parties would have been forced into coalitions with contemporary opposition parties (or forced to build a minority government). In fact, had the electoral systems followed our particular interpretation of proportional representation laws, the opposition parties would have “won” the elections in both countries!

Similar forms of aggregation bias in electoral systems can be found in the international political economy literature. In constructing a model of political change in an open economy, Garrett and Lang (1996) show, inter alia, how differences in electoral laws account for differences in the electoral weight assigned to various economic sectors and associated groups of voters. Assuming a change over time in the modal type of production from nontradable (less productive sector) to tradable goods and services (more productive sector) in an economy due to increased international economic exposure, electoral laws may benefit electorates associated with sectors which produce nontradable goods. In particular, this occurs in cases where geographic units (states or provinces) are used as the basic unit involved in voting rather than (changing) population weights, i.e., in case people migrate from states producing the less productive nontradable goods to states with more productive tradable goods - while the

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7 See Lijphart (1994, ch. 2) for a summary.

8 More complex measures of bias in electoral systems can be found in Lijphart (1994, 58-62).

distribution of votes across provinces remains frozen (Garrett and Lange 1996, 63-66; Lijphart 1994, ch. 2). Other forms of aggregation bias refer to thresholds of minimal electoral support in order to gain representation in parliament (e.g., a 5% threshold of votes). As a consequence of the disproportionality introduced by electoral systems, the number of parties being represented is reduced and the probability of victories by majority parties is enhanced (Lijphart 1994, 75).

While such aggregate results from election outcomes are well-known to comparative political scientists, they have also implications for cross-level inference in the field of international environmental policy. National governments are negotiating international environmental agreements and implement them by way of domestic laws. Since we often find sufficient differences in the preferences of national governments to negotiate such agreements (e.g., Sprinz and Vaahtoranta 1994), analogies to the aggregation bias introduced by electoral laws may be quite relevant in the environmental policy field.

Let us assume that voting on specific global climate change policies is organized in analogy to general elections, i.e., an electoral system transforms voting patterns of the general national public into voting patterns of the national government on the international level. As a consequence, majorities among national electorates in favor (or against) a particular proposal may be transformed into a minority. The same may apply to the international negotiations among groups of countries when considering particular policy proposals on global climate change.

The international community has agreed on the United Nations Framework Convention on Climate Change (UNFCCC), which does not entail obligations for developing countries to reduce their emissions of greenhouse gases. The same holds for the recently agreed upon Kyoto Protocol (Sprinz 1998). International negotiations at this level are typically conducted between groups of countries, represented by a lead country. Positions within a group appear to be determined in either of two ways: In order to propose a new position for consideration in the global negotiations, overwhelming support within the group is needed; in order to oppose a position of a different bloc, dissent by a comparatively small number of countries within one’s group is sufficient to make it the group’s position. On the aggregate level of all countries and groups of countries, only proposals which command close to universal support are carried. This aggregation procedure led to the conclusion that the proposed agenda item on “voluntary commitments by developing countries” was not admitted to the formal agenda of the Fourth Conference of the Parties of the UNFCCC (Buenos Aires, November 1998) because it received support predominantly by the hosting country, the USA and members of its group – but strong opposition from the leaders of the large grouping of developing countries (G77 plus China). Later speeches by national government delegates on behalf of their country revealed that there was a much more balanced sentiment within the group of developing countries regarding the admission of the topic to the formal agenda as compared to the presentations on behalf of this group of countries. In conclusion, rules of aggregation may lead to aggregation bias and distort the underlying distribution of preferences in the international environmental arena.

3. Methodological Approaches to Cross-Level Inference

As James S. Coleman reminds us

> A first observation is that good social history makes the transitions between micro and macro levels successfully (Coleman 1990, 21).

While this would be desirable, it is surprising to learn that sociologists do not necessarily attend to the problems posed by cross-level inference. Instead, descriptive ways of augmenting macro analysis by way of a micro analysis are suggested (e.g., Alexander et al. 1987). Coleman, for example, suggests a U-shaped macro-micro-macro path to improve on the macro-level explanation; i.e., the macro-level independent variable is related "downward" to a micro-level variable. Subsequently, the latter is used, in turn, as the exogenous variable in a micro-level explanation, and the micro-level outcome variable is related back "upwards" to the macro level variable to be explained (Coleman 1987; Coleman 1990, ch. 1). Surprisingly, none of the potential fallacies or mechanisms working at the stage of disaggregation (macro-to-micro) or aggregation (micro-to-macro; see Section 2) are seriously considered.

On the quantitative side, sociologists and political scientists have advanced the use of so-called hierarchical (linear) statistical modeling techniques which allow for nesting across levels of analysis (e.g., Bryk and Raudenbusch 1992; Hox and Kreft 1994a).

> The general concept is that the behavior of individuals is influenced by the social contexts to which they belong and that the properties of a social group are influenced by the individuals who make up that group (Hox and Kreft 1994b, 283).

This allows, for example, individual voting behavior to be explained not only by individual-level variables, but also by variables operating at a higher level of aggregation, such as macroeconomic variables (e.g., rates of unemployment or growth rate of the gross regional product) or the process by which borders of voting districts are drawn on partisan grounds (so-called gerrymandering) (see also Huckfeldt and Sprague 1993). When switching from individual level analysis to aggregate level analysis, it is important to include these aggregate level variables in the statistical analysis in order to avoid violating crucial statistical assumptions (e.g., independence of explanatory variables from the error term) which could lead to misleading results of the magnitude and sign of association between the independent and dependent variables. As Langbein and Lichtman eloquently summarize,

> Aggregate models used in lieu of individual data may be comprised both of variables which are theoretically relevant at the individual level and of variables which are added in order to remove the bias by grouping, i.e., variables that reflect the grouping process itself (Langbein and Lichtman 1978, 11).

More generally, Hanushek et al. (1974) suggest a more complete specification of aggregate models to reduce problems of aggregation bias - as found in the paradoxical results reported by Robinson (see Section 1).[9] However, aggregation does not always lead to problems of inference. In fact, departing from the definition of aggregation as the

> organization of elements of a system in patterns that tend to put highly compatible elements together and less compatible elements apart" (Axelrod and Bennett 1997, 72),

Axelrod and Bennett develop a "landscape theory of aggregation" to make predictions of the self-selection of countries into rival (e.g., military) coalitions (Axelrod and Bennett 1997). They assume that countries make myopic assessments of relations to each other and that change in alignments only occurs in an incremental way. Subsequently, they define a measure of the frustration or dissatisfaction of countries with each other. The latter is a function of the size or weight of other countries, the *propensity* of countries to be close to each other and the distance between countries. This measure of frustration is then incorporated in the assessment of configurations of coalitions. By searching for the minimum frustration across all sets of coalitions in a landscape graph, the sorting of countries into opposing alliances is predicted (Axelrod and Bennett 1997, 74-79).[10] The method provides a nearly perfect prediction of the alliance configurations of World War II with data for the period preceding this event. This method lends itself also to the prediction of business alliances, Parliamentary coalitions, and social cleavages in democracies. By carefully modeling the selection effects of units (countries) into aggregates (alliances or coalitions), problems of aggregation bias can be avoided.

Since the 1950s, two methods of cross-level inference have been advanced to make inferences on the (normally unobserved) individual level from (observed) aggregate level data (disaggregation or downscaling), thereby trying

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9 See also Bartels and Brady (1993, 128-130) as well as Huckfeldt and Sprague (1993, 285-286).

10 Given the starting conditions for such a search, there is no assurance that the local minimum found will also be the global minimum.

to circumvent the ecological fallacy problem advanced by Robinson: the "method of bounds" and Goodman "ecological regression."[11]

In essence, the "method of bounds" rests on accounting identities. For example, in explaining the association of Catholicism and the vote for the German National Socialist Workers Party (NSDAP) in the early 1930s, the following accounting identity can be derived:

$$Y_j = p_j X_j + q_j (1 - X_j)$$

with Y = % of the vote for the NSDAP, X = % Catholics in a voting district, p = proportion of Catholics voting for the NSDAP, q = probability of non-Catholics voting for the NSDAP, and subscript j = 1, ..., n represent different voting districts. Since data for Y_j and X_j are generally available, and since the proportions p_j and q_j have to fall into the interval [0,1], upper and lower bounds for q_i permit the deterministic derivation of the permissible range of values for p_j. Regrettably, this method often does not generate sufficiently narrow intervals for the proportions under consideration to yield interesting results by itself, and they cannot be statistically estimated due to underidentification problems (i.e., more unknowns than independent equations).

The latter drawback has attracted many researchers to Goodman "ecological regression," which overcomes the problem of underidentification with the help of strict assumptions: In general, the proportions p and q are set constant across all voting districts j.[12] While this allows conventional regression models to estimate both parameters, there is a major practical drawback: Parameter estimates often fall outside the logically permissible range, namely *below* 0 and *above* 1! As Achen and Shively suggest from a review of voter transition studies

> Logically impossible estimates in ecological regression are not flukes. They are encountered perhaps half the time, and more often as the statistical fit improves. Ecological regression fails, not occasionally, but chronically (Achen and Shively 1995, 75).

More recently, King (1997) has devised a way to fruitfully combine the deterministic results from the method of bounds with statistical estimation techniques in order to overcome the drawbacks posed by the two methods of

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11 Concise summaries of both methods can be found in Achen and Shively (1995) - from which the following examples are taken. See also King (1997, ch. 4).

12 A broad range of extensions and modifications of the basic Goodman model can be found in Achen and Shively (1995).

ecological inference introduced above. Unlike in Goodman ecological regression, King allows the p_j and q_j to vary across voting districts.[13]

King's modeling approach is conducted in four steps. First, based on the knowledge of aggregate data (X_j and Y_j), he develops a "tomography" plot with the help of the method of bounds. This plot includes all *possible* linear relationships between p_j and q_j for each of the voting districts j. In a second step, the means and standard deviations of p_j and q_j as well as the correlation between p_j and q_j are estimated *across* voting districts - yielding a "truncated bivariate normal distribution" from the known X_j and Y_j. Third, this particular distribution is superimposed on the plot generated in the first step. The contour ellipses stemming from the distribution in step 2 indicate into which range p_j and q_j are likely to fall into at the level of voting districts. Finally, in a fourth step, the truncated bivariate normal distribution (which was generated across voting districts) is used to generate distributions for p_j and q_j on the level of the j'th voting district in order to arrive at point estimates and uncertainty bands for these quantities of interest (ibid., 94-96).

This method of ecological inference has been verified with the help of examples where individual-level data are known (ibid., chs. 10-13). Using information from the deterministic method of bounds in combination with advanced statistical methods may generate plausible (and in the case of available individual-level data) verifiable results for the quantities of interests (e.g., p_j and q_j).

In essence, ecological inference derives information of a disaggregated nature when only aggregate level information is available. King's method (predominantly) does not work on different levels of aggregation as always individual voters are involved. But he imputes conditional characteristics that are previously unknown (e.g., % vote for the NSDAP given that the voter is Catholic) from aggregate information (% Catholics in a voting district, % votes for the NSDAP in a voting district) which is known. As compared to spatial downscaling found in the natural sciences, ecological inference in the social sciences often yields disaggregated information in the form of categories or characteristics of the unit of analysis which were hitherto unknown.

Although cross-level modeling is challenging, it also enables the development of new concepts. Following the pioneering work by Putnam (1988), which relates the positions taken by governments in international negotiations to properties on the subnational level (influential interest groups, the electorate, etc.), scholars of international relations have developed two-level

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13 King (1997) uses precincts to introduce his method and slightly different notation than introduced here. For ease of presentation, I will outline his ideas at the level of voting districts and keep the notation introduced earlier in this section.

game-theoretical models to formalize these relationships across levels of analysis in order to deduce new hypotheses (Iida 1992; Iida 1993; Schneider 1994; Schneider and Cederman 1994; Wolinsky 1994; Wolinsky 1997).[14] For example, Wolinsky (1994) develops a sequential, two-level game which relates governmental policies on signing international environmental agreements to electoral control; i.e., the electorate takes cues from a government's decision to sign or abstain from international environmental agreements in order to decide whether they are presently ruled by an effective or ineffective government. Other scholars have advanced the notion of the domestic prerequisites for international environmental negotiations (Hanf et al. 1996) or suggested a domestic-level argument about characteristics which induce countries to strive for international environmental agreements (e.g., Sprinz and Vaahtoranta 1994). Integrating levels of analysis proves to be a challenge both for game-theoretic modeling as well as statistical modeling; however, it permits the construction of models and the generation of insights which are more plausible than research conducted solely on a single level of analysis.

Besides problems of cross-level inference, a related problem arises, namely the choice of the optimal level of analysis - especially in the context of the study of human interactions with the environment. Rockwell (1998) makes a powerful case in favor of horizontally-linked meso-scale modeling. Should the nation-state serve as the appropriate unit of analysis, as is often found in international relations research? Especially in the case of large nation-states, Rockwell argues, countries may be too heterogeneous to provide a fruitful scale for modeling human-environment interactions. In addition, (legal) boundaries change considerably over time. Thus, a smaller level of aggregation on the meso-scale level would be preferable. Borrowing the idea from Otis D. Duncan, Rockwell suggests using samples representative of "POETic ecosystems" (Rockwell 1998, 483-484) to provide a functional interface for combined natural-social science modeling of the global environment.[15]

4. Conclusions

This article provides an overview of aggregation and disaggregation problems encountered by Political Scientists and the major methods used to solve such problems. Emphasis was placed on the ecological inference problem and its solutions as well as on problems of aggregation bias; the latter may have

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14 For a concise summary of this work with relevance to climate policy, see Sprinz and Luterbacher (1996, ch. 5.4.1).

15 The term POET refers to Population characteristics, social Organization, Environment, and Technology.

potential implications for the international negotiations on global climate change.

While cross-level inference is a challenge for the social sciences at large, it is not necessarily present when empirical observations across levels of aggregation are concerned. Axelrod and Bennett's "landscape theory of aggregation" (Axelrod and Bennett 1997, 72) and Sprinz and Helm's measurement concept for the effect of global environmental regimes (Sprinz and Helm forthcoming) are scale-independent – as are some models of geochemical cycles in the natural sciences. Thus, it is most important for the researcher to decide whether the particular problem under investigation involves potential problems of cross-level inference – and take steps to avoid inappropriate conclusions.

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