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Four views of "regional" in regional environmental change

Peter Cebon[a,*], James Risbey[b]

[a]Melbourne Business School, University of Melbourne, 200 Leicester Street, Carlton VIC 3053 Australia
[b]Department of Engineering and Public Policy, Carnegie-Mellon University, 5000 Forbes Avenue, Pittsburgh, PA 15213, USA

Abstract

For a number of reasons, mainly to do with data and computational insufficiency, a number of analysts are calling for regional models of global environmental change phenomena. This paper presents a typology for conceptualizing the dynamic relationship between the region being analyzed and the global system in which it is embedded. Regionalism can be convergent, divergent, local, or ambivergent. In addition to positing that regional phenomena can be modelled as a superposition of convergent, divergent, and local processes, it also shows that different regional specifications of a problem can lead to radically different analytical strategies, insights, and policy prescriptions.

Keywords: Regional analysis; Modelling; Climate change

In recent years, scientists and citizens alike have become more concerned about global anthropogenic environmental problems such as global warming and global ozone depletion. Traditionally, when analyzing these problems, particularly in their climatological and economic manifestations, scientists have tended to pursue a "top-down" approach. That is, they have tended to model the whole world at once, and then derive understandings of impacts and responses in local regions from the global analysis (e.g. Intergovernmental Panel on Climate Change, 1996). Such an approach is pragmatically sensible because the institutions that construct the policies and treaties for global environmental problems, such as the various conventions of the United Nations, tend to be global bodies. By having all work from the same analytic models, the playing field for negotiation is simplified (Alcamo et al., 1990), though not necessarily levelled. Furthermore, phenomena such as the El Niño/Southern oscillation (Bjerknes, 1969) has its of origin quite distant from its regions of manifestation. By including the whole world in models, these sorts of phenomena can presumably be captured.

Notwithstanding, there are significant problems with an exclusively top-down approach to the modelling of global environmental problems (Wigley, 1995). With general circulation climate models (GCMs), today's computers are still much too slow to allow calculations to be performed with the spatial resolution necessary to resolve some important regional features. For example, a small country like Switzerland would be represented by only about four grid points in the spatial grid of a GCM used to calculate the physical state of the atmosphere (i.e. air temperature, humidity, cloud cover, wind speed, etc.) (Imboden, 1998). Likewise, in a conventional GCM, the altitude of these four points would have to represent the country's complex topography. Needless to say, such a representation turns the massive Alpine peaks to harmless round hills of less than a 1000 m in altitude (Imboden, 1998). This shortening and smoothing of the peaks may well lead to modelling distortions that affect larger regions of the earth (Schaer et al., 1998). Furthermore, Alpine climate can vary drastically from one locality to another. Global models do not capture this fine structure. The result is that global models cannot capture some phenomena that are important to peoples' lives, such as the mean frequency of heavy rain events, or the anticipated mean snow cover, or the expected frequency of flooding at a specific locality (Imboden, 1998). Even if our computers were fast enough to drive models with sufficient spatial resolution — something which will not happen in the foreseeable future — we do not have nearly enough data with which to calibrate and initialize models effectively. The period of accurate data collection is relatively short, and the density of measuring stations

*Corresponding author. Tel: + 61-3-9349-8130; fax: + 61-3-9349-8133.

E-mail address: p.cebon@mbs.unimelb.edu.au (P. Cebon).

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is very low, especially in the oceans and the less-developed world. These same problems of computational and data insufficiency are probably more severe for social, economic, and botanical models than they are for climate models.

Given these problems with global models, among others, a number of analysts have turned to the production of regional environmental change analysis models (e.g. Cebon et al., 1998; Giorgi and Mearns, 1991). In a regional model, a particular geographic region is analyzed with a much finer grain made possible by denser data and smaller model sizes. A finer-grained analysis allows for the possibility of modelling processes and phenomena, and their interactions, which cannot be captured in a global model. Under some circumstances, this finer-grained analysis will produce substantially similar results to a global analysis. For example, the averages of the precipitation for all the sub-regions in a particular regional model might be the same as the average precipitation for the region in the global model. In these circumstances, the initial boundary conditions set by the global model end up being reproduced through regional processes. Under others, the following of a different path, or even finer-grained versions of the same path, will lead to fundamentally different results. These different results may indicate that the simplifying assumptions used in constructing the global model were poor or deceptive. Sub-regional phenomena, which have been 'assumed out' of the global model, may, in fact, have important global (or regional) influence. Alternatively, while different, these results may not be better. While a regional analysis gains by being more fine-grained and detailed, it loses in one key respect. Unlike global analysis, which is unbounded in space, regions have boundaries. Given that these boundaries are static, while the model is dynamic (if they were dynamic, they would be part of the model), the boundaries distort the model inputs. As a result, the difference in outputs may come from a mis-specification of the inputs at the boundary. Hence, while the two models are providing the best estimates of particular phenomena, we cannot privilege either. Rather, we must consider them as complements (Imboden, 1998).

The above discussion points to the need for regional analysts to be mindful of the relationship between the region under consideration and its boundaries, and hence the global system in which it is embedded. This paper proposes to facilitate that process by presenting a four-element typology of regional processes. While it is possible to posit that, within a given domain (e.g. climatology), any regional process can be modelled as a superposition of three of these, the paper has other purposes. First, it aims to show that different regional specifications of a problem can lead to radically different analytical strategies and insights. Because of this, people trying to understand the limitations of global models are likely to appreciate those limitations better, and therefore act on them, if they break regional phenomena into these three parts. Similarly, people working with regional models can gain a better appreciation of when they should privilege the regional over the global, and when, in contrast, they should privilege drivers from the global system. This will be illustrated with examples from climatological, biotic, and social systems. Second, it aims to show that different regional conceptualizations of a problem also can lead to radically different policy prescriptions. This will be illustrated by considering the way policies designed to reduce fuel consumption by automobiles change depending on the way the problem is conceived.

1. A typology of regional systems

The typology will be defined by the nature of the interaction between the regional system and the global system across the regional boundaries. In particular, we will be concerned with the flows of the information that drives the regional and global systems. In a convergent system, behavior at the regional level is driven from the global level. In a divergent system, behavior at the regional level feeds up to, and provides important influences on, behavior at the global level. In a local system, behavior at the regional level is essentially independent of behavior at the global level. In an ambivergent system, the global and the regional are driving each other simultaneously. This is illustrated schematically in Fig. 1.

In the remainder of the paper, we will characterize each type of regionalism, give examples from climatology, botanical systems, and socio-technical systems, and then present an example of public policy responses to the automobile problem based on that view of regionalism.

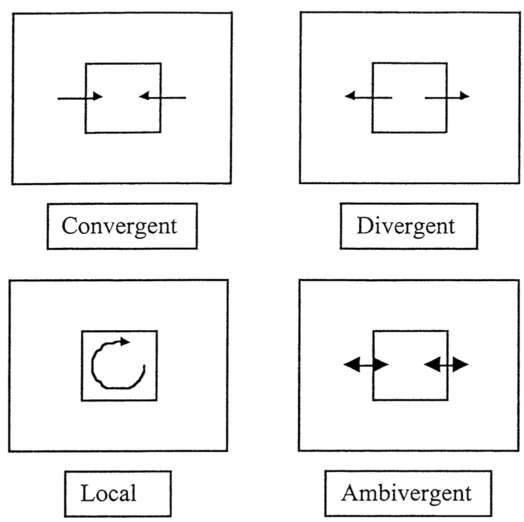

Fig. 1. A typology of regional phenomena.

2. Convergent regionalism

With convergent regionalism, the regional model is a "down-scaled" version of the global model. That is, regional parameters are transformations of global inputs. When analysts value the stock of a company, they tend to use a convergent approach. The determinants of the value of a company's stock, in order of importance, appear to be, the value of the global economy, the industry and country the company is in, and finally, of least import, is the quality of the management, staff, and products. In as far as this is true, it reflects highly convergent assumptions, and differs from our cultural presumptions that individuals create their own wealth and destiny through their actions.

There are two common methods for mapping a global system onto a region (Giorgi and Mearns, 1991). In the semi-empirical approach, a global model is used to describe the boundaries to a regional model, and then an empirical relationship is used to calculate local values. In climate models, an empirical relationship might be developed between the temperature at a given location and a set of climatic parameters for the region. A global climate model would then be used to estimate the change in those parameters over time, and the empirical relationship would be used to estimate the temperature at the location. When using modelling techniques, on the other hand, mesoscale features are described by increasing the model resolution only over the area of interest. This can be accomplished either by using a grid of variable resolution, or by so-called nesting techniques, where a higher-resolution region is embedded in a lower-resolution global model.

The work of Gyalistras et al. (1994, 1998) illustrates the semi-empirical approach to climate modelling. They construct climate scenarios involving 17 variables for five locations in the Alpine region. Their five-step method involves (1) selecting a set of predictor variables to be modelled using a GCM, (2) selecting a set of local variables to be predicted by the GCM, (3) using base-line data to derive an empirical relationship between the predictor variables and the predicted variables, (4) using the GCM to simulate climate and hence values for the predictor variables, and (5) applying the empirical relationship to the predictor variables to derive values for the regional variables of interest. Giorgi et al. (1994) illustrate this modelling approach when they drive a nested mesoscale model, with a horizontal resolution of 60 km, with a GCM. While the GCM provides the mesoscale model with information, the mesoscale model does not provide information back up across its boundaries to the GCM. This is known as "one-way" nesting, and is equivalent to assuming that the regional system behaves in a convergent manner. In principle, the nested model could also provide information on changes in regional parameters back to the GCM. This is known as "two-way" nesting, and is equivalent to assuming that the regional and global system behave ambivergently (see below).

Lischke et al. (1998) present two convergent models to simulate the response of vegetation to climate change. In the first, a static semi-empirical approach is used. That is, areas not subject to intense human usage are assumed to be in a quasi-stationary equilibrium at the moment. By sampling at a number of sites, the authors obtain estimates for the relationship between climatic variables on the one hand, and vegetation mix within the area of interest, on the other. New climate variables are then estimated and those estimates are used, in turn, to estimate new equilibrium vegetation. The second model represents a modelling approach which maps the interaction between the internal forces determining the vegetative composition of a small patch of forest of 1/12 Ha (29 m $\times$ 29 m) on one hand, and global forcing from the climate system on the other. Internal to the patch, the model simulates the germination, growth, and death of trees. All three processes are determined by a mix of global variables, such as climatic conditions, atmospheric gas composition, and a stochastic component interacting with light available on the forest floor. The available light is determined endogenous to the model, by the dying of trees. When each tree dies, the available seeds germinate and fight for the space left by the dead tree. Through such a process, the forest composition alters in response to changing climate.

Finally, most economic models of responses to climate change are essentially convergent models. In these models, demand for goods and services is assumed to vary as a function of local variables (e.g. wealth, regional growth rates, culturally given propensity to consume) and global variables (e.g. the set of available technologies, the global price level). For example, the Merge 2 integrated assessment model by Manne and Richels (1995) divides the world into five geopolitical regions: the US, the other OECD nations, the former Soviet Union, China, and the rest of the world. MERGE 2 uses a global algorithm to estimate that a doubling of CO_2 concentrations will lead to an increase of 2.5 K in global equilibrium temperature. A convergent methodology is used to estimate market and non-market impacts of these changes, greenhouse gas emissions, and impacts on GDP, while population changes are estimated exogenously. For example, to calculate market impacts, the modellers assume that an increase of 2.5 K would reduce the US GDP by 0.25% (after Nordhaus, 1991). For some regions, GDP is lost in proportion to projected temperature change (e.g. 5 K temperature change leads to a 0.5% GDP change). For China and the rest of the world, the cost is doubled. The modellers use peoples' wealth to calculate willingness to pay to prevent non-market impacts (e.g. on biodiversity, human health, and environmental quality).

As a convergent problem, the problem of automobile use reduces to one of managing the diffusion of an environmentally friendly technology (smaller cars) into a region, and moderating their use. Both the rate of purchase and the rate of use are assumed to be a function of a set of global variables (the price of cars, the price of gasoline) and local variables (wealth, quality of infrastructure, local taste in cars, etc.). If climate change is a convergent problem, then policy makers aim to use a treaty to impose changes on the global variables so as to alter local behavior at all locations. In the case of car use, the correct policy instrument is one that raises the price of fossil fuels so as to encourage people to buy smaller cars and use them less. A global carbon tax achieves this end. A more sophisticated version, tradeable carbon permits, allows the tax to vary as a function of location, according to its relative effectiveness.

3. Divergent regionalism

In divergent systems, there are important feedbacks from the regional level back up to the global level. The outputs from a regional model, when averaged over the region, do not produce the same answer as would come out of a global model which examined the same region. This means that if scientists were to construct a global model that averaged out these processes, the model might be in error, depending on what features one is interested in. The processes feeding up from the regional to the global level might well dominate the global processes being modelled already. The most cliché'd example of this type of phenomenon is the flapping butterfly of chaotic systems. Under certain conditions, the flapping wings of a butterfly (a very local event) are sufficient to tip the weather system into a regime whereby a hurricane is created on the other side of the planet (a more global event). If the butterfly does not flap, or flaps too early or too late, then the hurricane does not occur. Chaos is not the only driver of divergence. Many local feedback processes can combine to alter the global behaviour of systems. Similarly, insufficient computing power or data can produce divergence through rounding errors.

The butterfly example indicates that for some phenomena one can never be sure that the modelling scale is so small as to not have to worry about divergent processes. This is a particular problem in forecasting the weather, where small errors in characterization of initial conditions can grow to dominate a forecast. In the climate arena, chaotic effects are also important in setting the statistics of climate outcomes. However, the climate system is better characterized as a boundary value problem than as an initial value problem, and considerable forecast skill can be maintained in some regions if the boundary conditions can be specified accurately through time (Shukla, 1998). In biotic systems, which tend to be anchored to particular physical locations, attenuative processes almost always dominate. In social systems, where global markets and technologies can reduce the rate of attenuation by adding energy into the system at any point (e.g. through advertising), divergent processes can be highly significant.

Cebon et al. (1998) discuss two global-scale climatic phenomena which are captured poorly by global-scale climate models. Because of their geometry, air passing the Alpine ranges can either flow over them, or around them (Pahl-Wostl et al., 1998). In ranges that are very long, like the Rockies, the flow always goes over the top of the mountains. For isolated mountains, like volcanic islands, the flow generally goes around. However, for the Alps, the flow regime varies depending on the direction and strength of the wind, and on the previous history. The weather switches chaotically between the two regimes, with the switch being triggered by such things as changes in wind strength and direction, and the North Atlantic storm track hitting, or not hitting, the mountains. This switching between regimes has two important global-scale impacts. First, when the weather passes over the Alps, it sets up a standing wave that extends right across Europe into Eastern Russia, with an attendant impact on the weather there. When the flow passes around the mountains, the effect is much reduced. This effect is not captured effectively by global-level models because the chaotic dynamics are not captured well, and because the phenomenon is lost with the shortening of the mountains by model averaging. Second, the cyclones generated in the Gulf of Genoa (about 30 per year) strongly influence the weather over Northen Italy, and produce a secondary storm track that extends Eastwards either over the South-Eastern Alps, or over the Northern coast of the Mediterranean (Schaer et al., 1998). Because of the limited resolution of global models, these processes are either modelled poorly, or not at all, in current studies.

If we accept that precipitation changes are probably much more important to people and eco-systems than temperature changes, we realize how much of the regional picture is not captured by the global models. In the Alpine region, we are interested in changes in volumes, locations, time of year, of precipitation, and whether it falls as snow or rain. In the Winter, Autumn and Spring, the precipitation in the Alpine region itself and much of Europe is controlled by the location of the North Atlantic Storm Track, and the flow regime in place (over versus around the Alps). If the flow goes over the top, precipitation falls on the mountains. If the flow goes around, then there will be less precipitation, and it will fall to the North and South. However, which regime is in force, and the changes between them, also affects the amount of water drawn from the Mediterranean into the cyclones formed over the Gulf of Genoa, and therefore the amount of precipitation over the Eastern Alps and Northern Mediterranean. If we consider summer rainfall, the situation is similar, or even worse. Here, the precipitation is predominantly brought about by local thunderstorm activity strongly influenced by the geometry of the mountains (see discussion of local regionalism below). Finally, in both cases, much of the variance in annual precipitation can be attributed to extreme events. This kind of precipitation behavior is weakly captured by global-scale models (Grotch and MacCracken, 1991; Risbey and Stone, 1996).

In biotic systems, it is less common to see divergent processes, since ecosystems tend to have strong feedback systems built into them to prevent such processes occurring. One example, however, is the spread of disease. Some diseases, in certain conditions, can change their environment (generally by extending its boundaries) to increase their probability of propogation. McMichael et al. (1996) have discussed the way climate change may facilitate this process.

Divergent processes can be particularly important for the study of socio-technical systems. In an economic model, two key variables determine peoples' propensities to consume particular goods and services, namely the available technology and peoples' preferences. Economists have generally treated them as exogenous to the market. That is, the behavior of players within the market has no important effect on the technological changes that occur, or on goods and services people demand. However given the long time scales associated with the climate change problem, and given the way that preferences for products in less-developed countries are premised strongly on consumption patterns in the industrialized world, this is a very poor assumption (Truffer et al., 1998).

On the technology side, Truffer et al. (1998) discuss the invention and marketing of highly efficient automobiles (electric cars, hybrid cars). Under a convergent model, we would expect that existing automobile manufacturers would develop these. After all, they have the design, manufacturing, and marketing expertise. They also have the money to buy whatever expertise they lack. In contrast, most of the design and development work for these cars has been done in Switzerland. Truffer et al. argue that, in part, this is because Switzerland has no car industry! An existing industry would have attracted resources and talent away from the informal networks of car designers. A number of other factors specific to the region are seen as important drivers of the invention. These include very high quality engineering schools, wealth, a counter-culture interested in alternative transportation, a tradition of networked very small companies rather than dominant corporations, and effective networks of designers and users of experimental cars. These factors make Switzerland qualitatively different from other countries, and have enabled it to develop a qualitatively different technology. These factors are also not included in conventional economic models. Truffer et al. also argue that the technology will have the capacity to diffuse from the region to the rest of the globe if it offers increasing economies of scale at the level of the market. In particular, if increased use reduces cost, increases performance, and creates demand independent of price and performance (small eco-cars attract more status than high-powered gas guzzlers, or the presence of the cars increases that likelihood that regulators will mandate their adoption), then the chances of global diffusion are enhanced.

Strategic Niche Management (Kemp et al., 1998) is an example of a policy approach directed at encouraging divergent processes. Kemp et al. argue, consistent with the existing empirical literature, that a number of forces lock out the development and diffusion of new technologies. For instance, if someone wanted to sell electric cars, they would have to contend not only with the billions of dollars of development work which has gone into refining the basic petroleum car, but also the fact that petroleum cars are cheap because of their vastly greater scale of production. They would also contend with the fact that people will notice where the electric car intrudes into their lifestyle — a lifestyle they have constructed around the gasoline car's attributes (e.g. range, refuelling times). They may not notice the advantages, or potential advantages of the new technology (e.g. reduced noise, environmental amenity). Finally, we have a petroleum infrastructure (e.g. mechanics, fuel delivery systems, car experts who can tell us what to buy), which is only nascent for electric cars. Kemp et al. call the dominant technology, and these social institutions which surround it, a technology regime. They argue, quite accurately, that a nascent technology with the technical potential to completely supplant an existing technology will rarely do so. Similarly, a nascent technology that is cost competitive with an existing technology, in most cases, will almost always still fail. Instead, it will be locked out by the existing technology. A careful review of the literature of the history of technical evolution (Christensen, 1997; Elzen et al., 1996) indicates that, in many cases, radically new technologies do not burst forth onto the world scene. Rather, they occupy a specialized niche to which they are ideally suited. Within that niche, two things happen. First, the technology becomes progressively refined. Second, a regime is built up around the technology to support it. Over time, for some technologies, the niche grows. Sometimes, the new technological regime overwhelms the old one. So for example, the steam engine was initially only superior for pumping mines, solar cells found their first real application in electricity supply for sail boats, and the internet started as a communication tool for the military and researchers, particularly in highly globalized disciplines such as oceanography. Over time, as they became refined and their uses expanded, they occupied greater and greater niches. The Internet's niche has grown so large that it now threatens to displace the conventional telephone system — something unthinkable five years ago. Given this, Kemp et al. argue that governments and other groups that want to encourage the global expansion of nascent technologies such as electric cars should foster the creation and maintenance of niches. They lay out strategies for doing so. After a time, the market will, or will not, pick up the innovation and carry it forth. If it does not, they argue that support for the niche should be dropped in favor of alternative approaches.

4. Local regionalism

In the case of local regionalism, feedbacks internal to the regional system are so strong that changes in the global system are not transmitted into the region. Instead, they have no discernable impact. To give a simple example of this sort of behavior, imagine you owned an air conditioner. For a certain range of outside temperatures and humidities, the air conditioner would work to make the climate inside your home independent of the climate outside. Just as the air conditioner is only reliable between particular global limits, larger-scale systems also exhibit this behavior. If the global system goes outside those limits, then the regional system collapses, either into a convergent system, or into a local system in a different equilibrium. If it gets too hot outside, your air conditioner will not keep up, and so the internal temperature will start to rise with the outside temperature. The system would become convergent. If it stayed very hot for a prolonged period, the compressor on your airconditioner might burn out from over-use. In this case, the local system would collapse completely. In contrast, if the temperature dropped outside, your airconditioner may change to a completely different equilibrium, namely the heating cycle. Again, the inside temperature would be independent of the outside temperature, but the processes and feedbacks driving the local system would be radically different.

Micro-climates, particularly those inside dense forests provide an excellent example of local regionalism in a climate system. In these systems, some of which have very large extent, local processes create a climate that is essentially independent of that above the tree canopy – on shorter time scales at least. Similarly, (Schaer et al., 1998) discuss thunderstorm activity in the Alps in the Summer. While these systems are initiated, in an average sense, by global forcing, the actual storm systems, assisted by the local geometry of the mountains, develop a coherence which drives their ongoing behavior, and makes them relatively independent of the global regime which initiated them. Given that thunderstorms are the dominant source of Summer precipitation, and these processes cannot be captured by global models, this is a far-from-trivial phenomenon.

A cursory reading of the literature examining vegetative responses to climate change would seem to suggest that vegetative responses can simply be modelled as an arborial march towards the poles, pushed by an elevated temperature gradient (Roberts, 1989). The extent to which this is true varies by biome (A biome is a zone of similar vegetation, such as evergreen rain forest, boreal forest, tundra, or savannah.) Within each biome, plants exist in landscapes; within each landscape are communities; within each community are synusia. At each of these levels, the level of the synusia, community, landscape, and biome there are complex interactions between soils, fungi, bryophytes (lichens and mosses), vascular plants and the physical geometry. These interactions tend to create and limit the environments for the other elements. So, for example, within a synusia, the type of vegetative cover created by a particular tree. and the behavior of its roots, might give rise to particular understorey of vascular plants, fungi and bryophytes which, in turn, foster particular types of insects, particular types of soil evolution, and selection for particular genetic mutations. These behaviors are likely to favor the continuation of the tree and the flora beneath it, at the expense of other vegetation that we might expect to occupy the location given the climate parameters alone. This system is likely to be stable for temperatures quite far from its optimum (Theurillat et al., 1998). These interactions are more likely to mediate the direct influence of climate in some biomes than in others, e.g. rainforest rather than savannah. Furthermore, these plant communities feed back to influence climate on varying scales from the microclimates described above, through landscape and biome (Lovelock, 1979) to continental scales, such as the role of the Amazonian rainforest in transferring climatic anomolies from the Pacific to the Atlantic (Poveda and Mesa, 1997). Rather than a broad scale, variable-poor model with long run simulations, which might be used to model the evolution of a biotic system using a convergent approach (Lischke et al., 1998), local approaches to regional analysis of biotic responses require data-intensive empirical strategies coupled to highly detailed feedback-rich simulation models.

Finally, if we consider the problem of automobile transportation, the local problem looks radically different from the convergent problem of getting people to buy more efficient cars, or the divergent problem of fostering the development of radically new vehicle concepts. Instead, it moves attention to the vehicle in use. That is, analytically, we start to focus on services — the local services people require in order to function on a daily basis, and the transportation services people require to acquire those other services. So, for example, in our analysis of electric car users, we were struck by the importance of the Swiss rail system in peoples' decisions to buy and use electric cars. Electric cars are excellent city vehicles. However, they are too slow and have insufficient range for long-distance driving. Vehicle makers' usual response is to try to make them go faster and further. In contrast, we found that the Swiss users simply drove them to the station and caught the train whenever they wanted to go between cities. Because Switzerland has a frequent and extensive rail service, users appear to have been happy to substitute the greater comfort, spare time, speed, and safety afforded by the train for the inconvenience of having to go to the station, wait for trains, and possibly change trains at various times (Truffer et al., 1998).

While a convergent analysis leads us to solve global warming with carbon taxes, and divergent analysis pushes us towards strategic niche management, local analysis pushes us towards analysis and management of social infrastructure for the provision of services. At the first level, we can imagine policy analysts attempting to minimize the amount of transportation services people need. So, for example, we might have laws and social services which enable tele-commuting on one hand (so people would not commute), and discourage long-distance internet shopping on the other (to reduce transportation costs). At the second, they would focus on providing a diversity of transportation services that make it easy to use the most energy efficient transportation mode most of the time, while providing alternatives the rest. So, for example, they might focus on physically locating railway stations near commercial centers, and putting supermarkets in railway stations. They might also ensure that people have very good access to those rail services, by having good access to stations, clean efficient regular services, and services that run more frequently and later in the evening than might be suggested by an analysis of the public transportation system by itself. Similarly, at the time of the study of Truffer et al. (1998), the Swiss transport authorities were sponsoring very short-term (and cheap) car rentals to people who bought annual tickets. That way, if people needed a station wagon for 2 h to go to the timber yard, there were minimal barriers to getting one. This discouraged people from buying a station wagon for the two times a year they needed one. Another Swiss example is pooled, shared ownership of cars. Similar to time-share resorts, this pooled ownership gives people access to a car on a couple of weeks and a number of weekends a year, so they can take holidays or visit their aged aunt. Regular late-night bus services, especially on weekends, are also provided in some cities — though here the aim is generally to discourage drinking and driving. Notwithstanding, they radically increase the mobility of those who choose not to own a car.

As noted above, the aim is not necessarily to encourage people to use the train, which is the focus of much transportation policy, but rather to move the analysis from cars to the set of transportation services people require, and the most environmentally effective way of providing them. Given a broad enough set of complementary transport options, public transport, or an electric vehicle with limited range and speed, rapidly move from the bottom of peoples' mobility preferences to the top.

5. Ambivergent regionalism

In some systems, the flow of controlling information in one direction across the system boundary is as important as the flow in the other. This is ambivergence. Imagine, for instance, the flow of traffic over the official boundaries of a city which has long since transcended its original limits. Once upon a time, those traffic flows would have told us something about the movement of people and goods from the country to the city, and therefore about what makes the city different from the surrounding countryside. Now, after extended periods of sprawl, traffic flows across the original boundaries tell us little. While in most cities, a preferred direction of flow tells us which direction to look in, in order to find the country, in some cities, such as Los Angeles, the traffic flows across the original city boundaries have no directionality at any given time of day. The freeways are clogged in both directions. In this extreme case, the boundaries remove a degree of freedom while adding no information.

Note that ambivergence differs from a simple superposition of divergent and convergent regionalism. It is quite possible for convergent and divergent processes to occur simultaneously. For example in a given country, a government might be encouraging some people to develop high-performance electric cars for the world market while simultaneously encouraging the rest to buy fuel efficient conventional ones. This is a simple superposition of covergent and divergent processes and could be pursued through simultaneous strategic niche management and pricing policies. In contrast, the situation would be ambivergent if the government were trying to foster a local car industry producing cars that were essentially substitutes for the ones the country was importing. In such a situation, strategic niche management would conflict with price-based policies.

Ambivergence occurs when the flows of information across the regional boundary from the local to global and global to local are important, and are generated by processes that operate in both the global and the local domain. This can be because the system does not offer a useful boundary between the local and the global. The climatologists would argue, for instance, that while regional behaviors can easily be discerned, there is no minimum point on the energy gradient between global and local systems, and therefore no obvious place to partition the global from the local. Therefore, any separation of the two scales is essentially arbitrary. As such, any regional model must manage its ambivergent boundaries.

Alternatively, system drivers can span the boundary because the boundaries are selected for reasons other than analytical efficiency in the narrowest sense. In these cases, we typically need a global model just to specify the system boundary, and so the boundary hardly increases our analytical capacity. There are a couple of reasons why we might pursue such an analysis, nonetheless. First, if we are attempting a multi-disciplinary model, it may be that the appropriate boundaries for the regional system for one discipline differ from those for another. For instance, with the exception of island nations where they happen to coincide, political boundaries are not usually the most useful choices for climate analysis. Notwithstanding, for a host of reasons, we may want to base our climate analysis on political boundaries. Similarly, if we are looking at innovation behavior, Southern Germany, in many respects has more in common with Northern Italy than with Northern Germany (Truffer et al., 1998). But, in a whole lot of other ways, such as availability of resources, education systems, language, legal environment, etc., it has more in common with Northern Germany. Therefore, we might still choose to construct our analysis in terms of national boundaries.

The obvious analytical approach for constructing an analysis in the ambivergent case is to nest the regional model within the global one, and allow for a two-way exchange of information across the boundary. Remember that in one way nesting, the global model is run for a time period in order to produce boundary conditions for the regional one, and then the regional model is run using those boundary inputs. With two-way nesting, the outputs from the regional model are fed back into the global model as inputs. Two-way nesting presents problems in formulating conditions at the boundary of the global and nested model. The models will normally differ in spatial and temporal resolution at the boundary, and this discontinuity presents problems in harmonizing the respective models' parameterization schemes and flows of information across the boundaries. The discontinuity introduced by the boundary between the distinct models can be avoided in part by use of a single model to provide both global scale and local scale simulation. For example, Caian and Geleyn (1997) have developed a climate model in which a variable grid is used to provide high resolution over a region of interest (in this case France), and coarser resolution in other regions. While the nesting problem has been circumvented by use of a variable mesh grid, a new set of issues arise in modelling the movement of physical flow systems from coarse to fine-mesh regions and vice versa (Davies, personal communication, 1998). As such, the use of a variable grid does not overcome the problem of ambivergence. The model cannot resolve the boundary between the global and the local, in part because there is no natural boundary between the two.

6. Discussion. Selecting views of the regional

Much regional analysis for policy assumes convergent processes dominate, while much other regional analysis unreflexively assumes convergent, divergent, or local regionalism dominate. This paper indicates clearly that a key analytical trick is to identify cases when that simplification constitutes a legitimate and useful approximation and when a plurality of regional analyses is called for. The answer to that question is going to depend heavily on the systems, time scales, physical boundaries, and issues of interest, and will rarely have a clear yes/no answer. Suffice to say that the regional framework adopted colors what we do and do not see, and shapes the representation of cause and effect. As such, the selection of regional framework is non-trivial. As a first step, we can begin to locate and identify our choices and simplifications in this regard.

A tropical rainforest provides a good example of the way in which selection of regional framework can be adjusted to address the dominant processes operating in relation to specific issues and temporal scales. On the shortest time scales of days, we saw above that we might usefully model the Amazon rainforest as a local system recycling moisture within a relatively closed system. On intermediate seasonal time scales we might be concerned with predicting the precipitation regime in the Amazon basin. In this case we would include a focus on fluxes of heat and moisture into and out of the Amazon region as a result of movements of air masses into and across the basin from adjacent land and ocean areas. The influence of sea surface temperatures and prevailing atmospheric circulations originating outside the basin may precipitate wetter or drier than normal conditions in the basin. This effect in turn might be moderated or exacerbated by local moisture recycling, and by land–ocean circulations induced across the basin and surrounding ocean areas. In this case, the processes of interest span and feedback on a range of spatial scales, and the Amazon basin might best be viewed and represented as an ambivergent system (e.g. Dickinson, 1987). On the time scale of years we might view the Amazon basin as a divergent system if we are interested in how changes in albedo and the hydrological cycle in the basin influence broader scale climatic features. This view is encapsulated in literature on the effects of Amazonian deforestation on climate (Henderson-Sellers and Gornitz, 1984). The convergent approach is represented by studies of the effect of enhanced levels of CO_2 on the Amazon in GCMs and by many paleoclimate studies of tropical climate (Dickinson and Virji, 1987).

In the above example of the Amazon basin, the issue or problem of interest varies somewhat at each of the different temporal scales examined, and there is a single framework that seems reasonable and appropriate to apply in each case. However, for many problems of interest it often turns out that there are multiple frameworks that each seem reasonable to apply to the same issue, as in our discussion of transportation policy. The idea of ambivergence suggests that some cases may prove intractable to such disaggregation. In these cases it is particularly important to identify the frameworks chosen (convergent, divergent, local) and their concomitant limitations.

Economic models of abatement potential through energy conservation also highlight the importance of this choice. Currently, two types of models dominate. One is essentially top-down and makes convergent assumptions; the other is essentially bottom-up and makes divergent assumptions. The proponents of the two types of models seem to spend a lot of time talking past each other. In top-down models, energy supply options, costs, and paths are typically prescribed, and energy demand is linked to larger scale macroeconomic indicators such as the growth of the economy and the assumed change in energy intensity/efficiency of the economy as a whole. The costs of reducing fossil emissions from the energy sector may then be calculated by matching supply and demand and imposing a policy lever such as a tax on the price of fossil energy. This convergent approach has tended to produce rather pessimistic projections of the prospects for cheap abatement of CO_2 emissions (Morgan and Dowlatabadi, 1996). In this case, the pessimism tends to reflect the range of assumptions employed about choices made, rather than following necessarily from use of a convergent methodology. Notwithstanding, the convergent approach biases models towards currently existing practices and technologies by implicitly representing any forced technological changes as a drag on economic growth (Ayres, 1994). In the "bottom-up" models, efficiency gains are calculated by integrating from individual technologies up to the larger economy (e.g. Lovins, 1977). This engineering approach tends to produce much more optimistic estimates on the costs of abating CO_2 emissions, partly as a result of making optimistic assumptions about the diffusion of new technologies.

7. Conclusions

Despite extensive pleas for regional analysis for climate change, and a burgeoning literature, much of that literature is very confusing. Most analysis we have read seems to fall into one of two camps. One group automatically sub-ordinates the regional to the global (a convergent analysis as defined above) or essentially ignores the global altogether (a local analysis), and loses much of the richness the regional offers. The other group does not make any such simplifying assumption, and the reader is left disoriented, not knowing what is important, or more to the point, what has been left out. Our first aim, in producing this simple categorization, has been to give readers and scholars alike a rough and ready roadmap for thinking about the regional problems they examine, and their relationship to global problems. Our aim in constructing this framework has been to be as uncontroversial as possible. We hope that this framework will help peoples' thinking, and our belief is that a simple framework which everyone can understand and explain will be most useful for that purpose.

Our second and third aims have been much more activist. By drawing a sharp distinction between the first three types of regionalism: the convergent, the divergent, and the local, we have attempted to show how radically different a given problem can look from the three perspectives. In three different domains, climatology, vegetative ecology, and transportation usage, we have seen that the same broad phenomenon, cast from three different perspectives, points towards radically divergent insights. So, for example, transportation planning changes from a problem of understanding the diffusion of globally developed fuel-efficient cars to one of understanding the characteristics of a particular region which make it amenable, or not, to developing radically new technologies with the potential for global reach, to understanding how, when considering technology in use, it may make sense to divorce ourselves from the hardware altogether, and focus, instead, on the services used in a given society.

Our third aim has been in the area of public policy. Here, it is our feeling that the convergent approach, and the assumption that its assumptions should dominate the policy agenda, have overwhelmed the debate. We see this both in the analytical assumptions (such as the assumption that prices are sufficient drivers of innovation) and the policy prescriptions given currency (particularly tradeable permits). Our hope, in pointing out that there are equally valid alternative ways of looking at the problem has been to broaden the debate and open up consideration of alternatives.

Our discussion of ambivergent regionalism has served, we hope, to sound a word of caution. While in many cases, it is possible to talk about different forms of regionalism, and often we can distinguish them, our ability to model them independently and then superpose them relies on their being relatively independent. As they become more interdependent, this assumption becomes less plausible. In these cases we move further and further towards the ambivergent case, and all the analytical difficulties which come with it.

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