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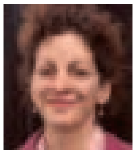
UNDERSTANDING PUBLIC COMPLACENCY ABOUT CLIMATE CHANGE



Critical public policy issues increasingly involve complex physical and natural systems. While we all hope that societal responses to such challenges are based on the best available scientific knowledge, increasingly, effective responses to important public policy issues require changes in the beliefs and behaviours of the citizenry at large. Science tells us that seatbelts save lives and that smoking causes cancer, but if members of the public don't understand why, they may ignore the best scientific advice. If widely-held mental models of complex systems are faulty, people may inadvertently favour policies that yield outcomes they neither intend nor desire.

Climate change is such an issue. Opinion polls show an apparent contradiction in public attitudes toward climate change: a majority of citizens support the *Kyoto Accord* and *Climate Stewardship Act*, believe human activity contributes to climate change, and desire to limit the risk of harm from it. Yet at the same time, large majorities oppose mitigation policies, such as energy taxes.

Many people advocate a 'wait and see' strategy: when asked to choose which of several statements came closest to their own view, nearly 60 per cent chose either, "until we are sure that global warming is really a problem, we should not take any steps that would have economic costs," or "its effects will be gradual, so we can deal with the problem gradually."

In the case of the climate, we can't wait until the damage is (more) visible than it already is before taking action. You can't buy insurance after a disaster. Similarly, protecting ourselves and our children from the risks of climate change requires emissions reductions today. Waiting to see how bad climate change is going to get is like waiting until after your house burns down to get insurance. So why, then, do so many people advocate a 'wait and see' approach?

Why 'Wait and See' Won't Work

Rather than assuming people are short-sighted and selfish (the usual explanation), we should ask instead what the world would have to be like for wait-and-see to be a prudent response to the risks of climate change. The answer is time delays. Wait-and-see policies often work well in simple systems – those with short lags between the detection of a problem and the implementation and impact of corrective actions. In boiling water for tea, for instance, one can wait until the kettle boils before taking action, because there is essentially no delay between the boiling of the water and the whistle of the kettle, nor between hearing the whistle and removing the kettle from the flame. Few complex public policy challenges can be addressed so quickly. Wait-and-see would be a prudent response to the risks of climate change if we could quickly stop it once we saw how harmful it will be. Doing so would require short delays in all the links in the long causal chain, stretching from the detection of adverse climate impacts, to the decision to implement mitigation policies, to emissions reductions, to changes in atmospheric greenhouse gas (GHG) concentrations, to radiative forcing, to surface warming and finally to climate impacts, including changes in ice cover, sea level, weather patterns, agricultural productivity, the distribution of species, extinction rates, and the incidence of diseases, among others.

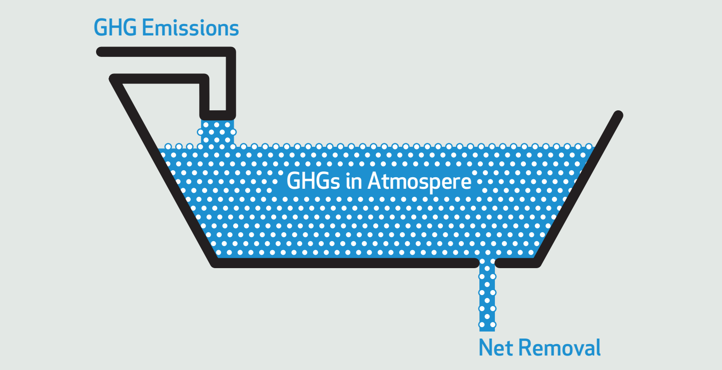
None of these conditions hold. In fact, there are long delays in every link of the chain. Some of the response delay arises from the time required to develop scientific understanding of the climate and the way human activity is changing it. That question is now settled – the **Intergovernmental Panel on Climate Change** (IPCC) has just released its latest report, concluding that "warming of the climate is unequivocal" and that "most of the observed increase in globally averaged temperatures since the mid-20th century is very likely due to the observed increase in anthropogenic greenhouse gas concentrations" (see the IPCC Summary for Policymakers at www.ipcc.ch). But scientific consensus is not enough: there are additional delays required to build the public and political support needed to pass legislation and ratify international agreements. There are then additional lags between changes in policy and changes in emissions – even after automakers are able to develop alternative fuel vehicles it will still take decades to turn over the existing fleet of cars that burn gasoline. Infrastructure and settlement patterns change even more slowly.

The longest response delays, however, arise within the climate itself from the 'stock-and-flow' relationships among GHG emissions, GHG concentrations, and global mean temperature. Two stock-flow structures are fundamental: global mean surface temperature integrates (accumulates) net radiative forcing (minus net heat transfer to the deep ocean); and in turn, radiative forcing is affected by the level of GHGs in the atmosphere, which integrates emissions less the rate at which GHGs are removed from the atmosphere.

GHG emissions are now roughly double the net rate of GHG removal by natural processes, which include net uptake by biomass, the ocean, and other 'sinks.' Even if policies to mitigate climate change caused these emissions to fall, atmospheric GHG concentrations would continue to rise until emissions fell to the removal rate. GHG concentrations can fall only if emissions drop below removal. Warming would continue until atmospheric concentrations fell enough, and global mean temperature rose enough, to restore net radiative balance. Global mean surface temperature would then peak, and climate changes such as sea level rise from ice melt and thermal expansion would continue.

The belief that wait-and-see policies are prudent implicitly presumes that the climate is roughly a first-order linear system with a short time constant, rather than a high-dimensional dynamical system with long delays, multiple feedbacks and non-linearities that might cause abrupt, persistent and costly changes.

Atmospheric Greenhouse Gases (GHGs) Figure 1



Understanding Stocks and Flows

Why do people underestimate the time delays in the response of climate to GHG emissions? Obviously, the average person is not trained in climatology, and studies document low levels of public understanding of climate processes. We hypothesize, however, that widespread underestimation of climate inertia arises from a more fundamental limitation of people's mental models: a weak intuitive understanding of stocks and flows, and the concept of accumulation in general, including principles of mass and energy balance.

Prior work shows people have difficulty relating the flows into and out of a stock to the trajectory of the stock, even in simple situations such as filling a bathtub or managing a firm's inventory. Instead, people often assess system dynamics using a 'pattern matching' heuristic, seeking correlations among the data and using these to project future values.

Pattern matching often works well in simple systems, but fails in systems with significant stock-and-flow structures: a stock can rise even as its net inflow falls, as long as the net inflow is positive. For example, a nation's debt rises as long as its fiscal deficit is positive, even as the deficit falls; debt falls only when the government runs a surplus. Since anthropogenic GHG emissions are now roughly double net removal, atmospheric GHGs would continue to accumulate, increasing net radiative forcing, even if emissions drop – until emissions fall to net removal (of course, removal is not constant; we consider the dynamics of removal below).

In contrast, pattern matching incorrectly predicts mean temperature, and atmospheric GHGs closely track emissions; hence stabilizing emissions would rapidly stabilize climate, and emissions cuts would quickly reverse warming and limit damage from climate change. People who assess the dynamics of the

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climate using a pattern-matching heuristic – projecting past correlations among emissions, CO_2 concentrations, and temperature – will significantly underestimate the lags in the response of the climate to changes in emissions and the magnitude of emissions reductions needed to stabilize atmospheric GHG concentrations.

We recently conducted experiments to determine the extent to which highly-educated adults understand the fundamental relationship between flows of GHGs and the stock of GHGs in the atmosphere and found significant misperceptions of basic climate dynamics in a population of graduate students at an elite university.

Pattern matching was widespread; worse, a large majority violated fundamental physical constraints, including conservation of mass. Most believed atmospheric greenhouse gas concentrations can be stabilized even as emissions into the atmosphere continuously exceed removal of GHGs from it, analogous to arguing that a bathtub filled faster than it drains will never overflow. These beliefs favour wait-and-see policies, but violate basic laws of physics.

An evolutionary perspective may shed light on why pattern matching dominates stock-flow reasoning. Decision-making consumes scarce time and cognitive resources. Selection pressures favour the evolution of 'fast and frugal' heuristics that are successful to the degree they are ecologically rational, that is, adapted to the structure of the information in the environment in which they are used. The overwhelming majority of everyday experience involves simple systems where cause and effect are closely related in time and space, time delays are short, and information cues are highly correlated. The water in the teakettle boils and the whistle sounds; eating certain mushrooms is quickly followed by illness. The ability to detect correlations among cues in the environment is highly rewarded, and people's judgments about causal relationships are strongly conditioned by proximity and co-variation.

In contrast, it is not necessary to understand stocks and flows to fill a bathtub – the water accumulates 'automatically.' It is far more efficient to watch the water in the tub and shut off the tap when it reaches the desired level. For a wide range of everyday tasks, people have no need to infer how flows relate to stocks – it is better to simply wait and see how the state of the system changes, and then take corrective action.

Wait-and-see is therefore a valuable heuristic in common tasks with low dynamic complexity, where delays are short, outcome feedback is unambiguous and timely, opportunities for corrective action are frequent, and the costs of error are small. None of these conditions hold true in dynamically complex systems like the climate, where there are multiple positive and negative feedbacks, delays between actions and impacts are long, outcome feedback is ambiguous and delayed, many actions have irreversible consequences, and the costs of error are potentially huge.

The Quest for Understanding

When policy implementation depends on widespread citizen understanding and behaviour change, risk communication is as important as risk assessment.

Perhaps people understand stock-flow relationships but are unable to apply their knowledge to climate change due to inadequate background knowledge of climate and GHGs. If that is true, education about the sources of GHGs, the biogeochemical cycles that regulate them, and their role in radiative forcing would overcome the problems observed here.

While surely needed, such education is not sufficient. Prior research shows pattern matching and violations of conservation principles are prevalent in much simpler contexts requiring no specialized background knowledge, for example, filling a bathtub. In a prior study, we presented subjects from the same elite university population with a picture of a bathtub and graphs showing the inflow to and outflow from the tub. Extremely simple patterns for the inflow and outflow were used, and more than half violated the most basic stock-flow relationships – for example, failing to show that the water level rises when inflow exceeds outflow, and falls when outflow exceeds inflow.

Better information on climate or the carbon cycle is unlikely to overcome weak knowledge of stocks and flows and consequent violations of conservation laws in intuitive assessments of policies to address climate change. These flawed mental models support the belief that it is best to wait and see if further warming will be harmful before supporting action.

Misconceptions of stocks and flows may be an important part of the explanation for the contradiction between the public's desire to limit climate change while simultaneously arguing for wait-and-see policies that ensure the anthropogenic contribution to climate change continues to grow.

The pervasive violation of these physical principles stands in contrast to the common explanation that people oppose stronger actions to cut emissions because they are short-sighted and self-interested, discounting the future at high rates. Rather, people may simply, but erroneously, believe that stabilizing emissions quickly stabilizes the climate.

The Role of Risk Communication

It would be naive to suggest that educating the public about stocks and flows would somehow cause people to suddenly support emissions reductions consistent with their avowed desire to limit the risks of harmful climate change. Successful implementation of policies based on 'the best available science' is a process of knowledge diffusion and social change that involves word of mouth, imitation of trusted authority figures and respected elites, media influence, and emotions, not only rational judgments of costs and benefits.

The adoption and diffusion of innovations, whether new products or new beliefs, is facilitated when the innovation is simple, easy to test, has clear advantages over alternatives, and where costs and benefits are quickly and easily observed. Climate change ranks poorly on all these dimensions: it is complex, policies are difficult to test, and the benefits of emissions reductions are delayed and ambiguous. When people cannot readily assess costs and benefits for themselves, and when they are unable to interpret the best available scientific evidence, imitation of elite reference groups, word of mouth, media and marketing play stronger roles in opinion and behaviour change.

Effective risk communication strategies are tailored to suit the mental models of the audience. As **Granger Morgan**, a risk communication expert at Carnegie Mellon University, and colleagues argue, "Rather than conduct a systematic analysis of what the public believes and what information they need to make the decisions they face, [policymakers] typically ask technical experts what they think people should be told.... Those passing judgment may know very little about either the knowledge or the needs of the intended audience. Under such conditions, it is not surprising that audiences often miss the point and become confused, annoyed, or disinterested. If the communicators feel that they have done everything that is expected of them, they may conclude that their audience was responsible for the communications failure."

Most scientific and popularized accounts of climate change do not present the fundamental stock-flow relationships among emissions, removal, GHG concentrations, radiative forcing, and temperature in ways the highly educated subjects here, much less the public at large, can understand. The language is highly technical, requiring knowledge of terms such as CO^2, gigatons of carbon equivalents, ppm, radiative forcing, albedo, and so on. Overwhelmed by technical detail, people's mental models lead them to rely on pattern matching and correlations rather than stock-flow reasoning. Effective communication about climate change should help people understand these relationships in familiar terms.

Pictures of stock-flow structures such as bathtubs with tap and drain have proven effective in fostering greater understanding and policy change in a number of settings, from automobile leasing to the war on drugs. The prevalence of basic misconceptions about stocks and flows among highly-educated subjects suggests the climatology community should consider similar representations in communications designed for both the public and policymakers.

In Closing

Successful implementation of policies to address problems such as climate change requires broader public understanding of the need for emissions reductions. Building that understanding requires that we first understand the mental models ordinary folks use to think about the issue, and then create learning environments in which people can discover, for themselves, the relationships among greenhouse gas emissions, atmospheric concentrations, and the climate.

Our research shows that even highly educated people erroneously believe that emissions, atmospheric concentrations, and climate are highly correlated. This belief leads to the erroneous conclusion that a drop in emissions would soon cause a drop in CO_2 concentrations and mean global temperature. Mean surface temperature keeps rising as long as radiative forcing (minus net heat transfer to the deep ocean) is positive, even if atmospheric CO_2 – and hence net forcing – falls. Atmospheric CO_2 keeps rising even as emissions fall – as long as emissions exceed removal. Because emissions are now roughly double net removal, stabilizing emissions near current rates will lead to continued increases in atmospheric CO_2. In contrast, most subjects believe atmospheric CO_2 can be stabilized by stabilizing emissions at or above current rates, and while emissions continuously exceed removal.

Such beliefs – analogous to arguing a bathtub filled faster than it drains will never overflow – support wait-and-see policies, but violate basic laws of physics.

People of good faith can debate the costs and benefits of policies to mitigate climate change, but policy should not be based on mental models that violate the most fundamental physical principles. The scientific community must devote greater resources to developing public understanding of these principles to provide a sound basis for assessment of climate policy proposals.

An interactive simulator to help people understand stocks and flows is available online at: http://web.mit.edu/jsterman/www/GHG.html. **R**

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