Creating Value in the Global Weather Enterprise

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Technical Note from the series on specific aspects of Public and Private Engagement in Hydromet Services

Abstract

The global weather enterprise creates high value weather and climate information that produce a wide range of social and economic benefits, including the protection of citizens and infrastructure from natural hazards. The creation of value derives from the global cooperation of many actors in the public, private, and academic sectors.

The incentive to develop and improve national meteorological ecosystems revolve around the social, socioeconomic, and economic benefits of the weather enterprise. While meteorological infrastructure investment is critical, it is also as important to address issues such as design of market structures conducive for value creation, enhancing legislative and regulatory frameworks, and accounting for value creation in the public, private, and academic sectors. This technical note examines the ways in which the structure and operation of the weather market can maximize the creation of value.

Significant economic advantages result from establishing clarity in, and a greater recognition of, the value each producer creates. This would incentivize fair competition, pervasive cooperation, and greater exploitation of coproduction.

Introduction

Weather and climate information[1] has high value and a convenient and popular way to describe the global weather enterprise[2] as a value chain. A theory of value has been a foundation of many schools of economic thinking and some leading economists (Mazzucato 2018; Carney 2021) have underlined the benefits from viewing the economy through a value lens. These benefits include a reappraisal of the role of the public sector in value creation and of the relationship between price and value of goods and services.

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Recognizing value as being at the heart of the global weather enterprise could facilitate more productive cooperation, collaboration, and partnerships between actors in the public, private, and academic sectors.

In economics, value creation occurs when new and useful goods and services are produced, and their value relates to their usefulness.

This technical note posits that value creation can provide a unifying perspective linking the multitude of activities that produce meteorological information and clarifies the many diverse relationships between actors from across the public, private, and academic sectors. A shared understanding of value creation has the potential to help dispel any myths and increase trust between participating organizations.

A fundamental characteristic of the weather enterprise is that it takes place within an environment of meteorological globalization; yet it also depends on legislation and economic policies enacted at the national level. The complex interplay between organizations from the three sectors within national and international contexts is central to the global weather enterprise (Thorpe and Rogers 2018). Recognizing explicitly the value produced by each actor and establishing a clear framework within which actors operate and interact are ways to promote further growth of the enterprise.

This technical note explores what constitutes value, who creates it, and how it might be measured. Recognizing value as being at the heart of the global weather enterprise could facilitate more productive cooperation, collaboration, and partnerships between actors in the public, private, and academic sectors. Such cooperation is crucial if the many benefits of weather information are to be fully realized; a point foreshadowed in the World Meteorological Organization's (WMO) Geneva Declaration[3] of 2019 that commits WMO Members to enhancing cooperation across the sectors.

Global atmosphere and local impacts

Weather itself is a global phenomenon because the Earth's atmosphere is in perpetual motion circulating globally, but one that is experienced locally by people. Weather events here and now have had their roots in far remote regions some days or even weeks and months previously. This is dictated by the laws of physics and chemistry, and biological processes that determine the inherent time and spatial scales of the atmospheric fluid. Consequently, even though weather affects people and so is perceived as a local phenomenon, no single person, organization, or country can produce all the weather information they need by thinking and operating purely locally. The atmosphere, and so meteorology, is global.

The implication of the global atmosphere for the weather enterprise is that while individuals, organizations, and nations are, in principle, independent agents they all must operate *perforce* within a global framework—each actor is to a greater or lesser extent dependent on the global framework.[4] This leads to an economic process of meteorological globalization. This is the process by which the whole world operates as a single or aggregated market for weather information.[5] This means that weather goods and services, capital, and labour are traded on a worldwide basis and information and the results of research flow readily between countries. Such trading encompasses both financial and nonfinancial transactions. The interplay between national and international aspects of the weather enterprise is therefore a fundamental issue.

Discussing the meteorological endeavor as a market or an enterprise may seem to some as only looking through a commercial lens; however, this is not the intention. In this technical note, we aim to consider a very broad concept of the weather market or enterprise to encompass all actors who participate in the production of weather information whether they are in the public, private, or academic sectors. The roles of actors from each of these three sectors need to be synergistic and of mutual value.

Meteorological value

The modern concept of value is about the utility or benefit of goods, data,[6] or services to whomever uses them. An important consequence of this definition is that value is not equal to the financial cost of producing or the financial benefit of using that data although clearly, they are related. Furthermore, some of the benefits of using the data are intangible and so likely incapable of monetization—while some also have tangible benefits that are fully quantifiable in monetary terms. In summary, this definition of value indicates that utility determines value, which, in turn, determines the price of data, goods, and services. Consequently, the value created from the weather enterprise can be seen to intrinsically produce social, socioeconomic, and economic benefits.[7]

Although the idea of a value chain has existed for some time when analyzing manufacturing firms,[8] it has also become common practice in many other sectors, including meteorology—a climate services value chain can be found in Brasseur and Gallardo (2016). It has profound implications not only in describing how the weather enterprise operates but also in the underlying economic framework. There have been several approaches to analyze costs and benefits in the weather enterprise such as via cost–loss model (Maunder et al. 1997), contingent values (Lazo and Chestnut 2002) or weather service chain analysis (Nurmi et al. 2013). This technical note aims to examine the global weather enterprise holistically as value creation.

The weather value chain has profound implications not only in describing how the weather enterprise operates but also in the underlying economic framework.

The basic idea of a weather value chain is to imagine a sequence that begins with making observations of the global atmosphere using the Global Observing System.[9] Such observations have great value firstly, because they inform us about the state of the atmosphere at given times and places. However, their value is added to by merging the observations with a prior short-range prediction of the prevailing state of the atmosphere to fill in the gaps in the observational network. This involves a process called data assimilation and a global predictive numerical weather prediction (NWP) model (Bauer et al. 2015). This globally consistent and homogeneous dataset is used for the initial conditions for NWP predictions—using the laws of physics and supercomputers—of the future weather, which is another step that adds value. Turning those NWP datasets into meteorological forecasts is a further value-adding step. Tailoring such meteorological predictive data into services that target customer needs takes the next step. Finally, organizations can carry out business and public data integration,[10] or more concisely integrated services, whereby those meteorological data are merged with data from other domains such as energy production, traffic flows, Internet of Things, or population density to create information that most directly helps people live their daily lives.

A crucial additional element in the meteorological value chain concept that is not usually made explicit is the creation of new knowledge—via research and innovation—often referred to as science and technology, and also encompassing social science, humanities, and economic theory, among other things. Knowledge is an input to all the links and not just in one position in the chain. It is important to recognize knowledge as also having value in its own right as well as allowing further value to be created down the chain—humans value knowledge as an intellectual good in its own right. Without new knowledge the value chain would stagnate because innovation would stop and would not match the growing and ever more sophisticated user demands. So, knowledge creation is at the heart of the enterprise.

A good way to describe the meteorological value chain is that each link in the chain creates value and this adds to the total stock of value of the enterprise. While the process of building on the input from the previous link is important—and a missing link in the chain prevents some or all the value being realized—the value chain is not merely a process accumulating value sequentially to an endpoint of the highest value.

In Figure 1, the various links in the weather value chain indicate that value created in each link can feed into the next link thereby adding further value. Also, knowledge creation, such as via science and technology innovation, is an essential input that enables the value in each link of the chain to be derived. Social and economic benefits arising from the value chain result from the value created.

Figure 1: The meteorological value chain.

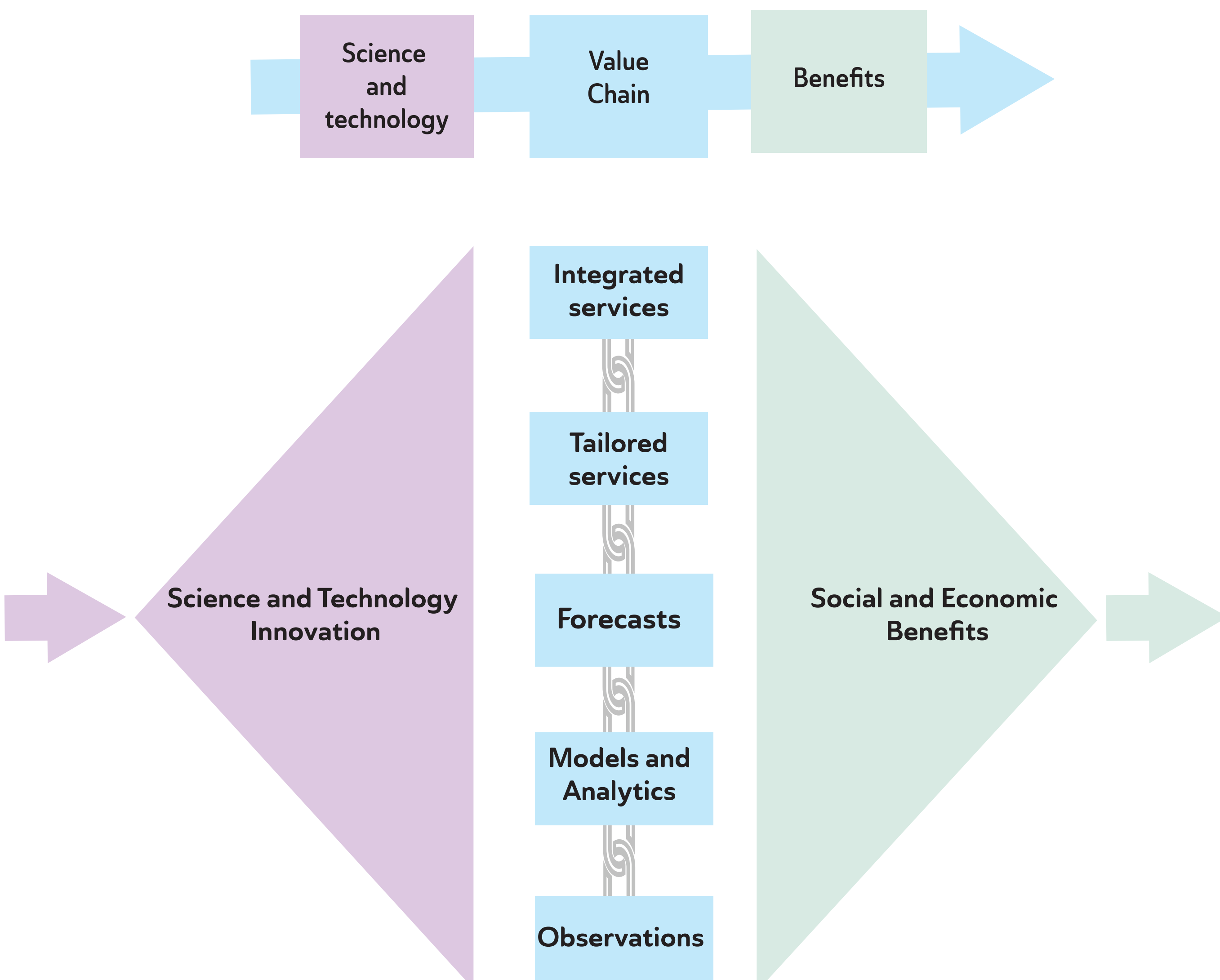
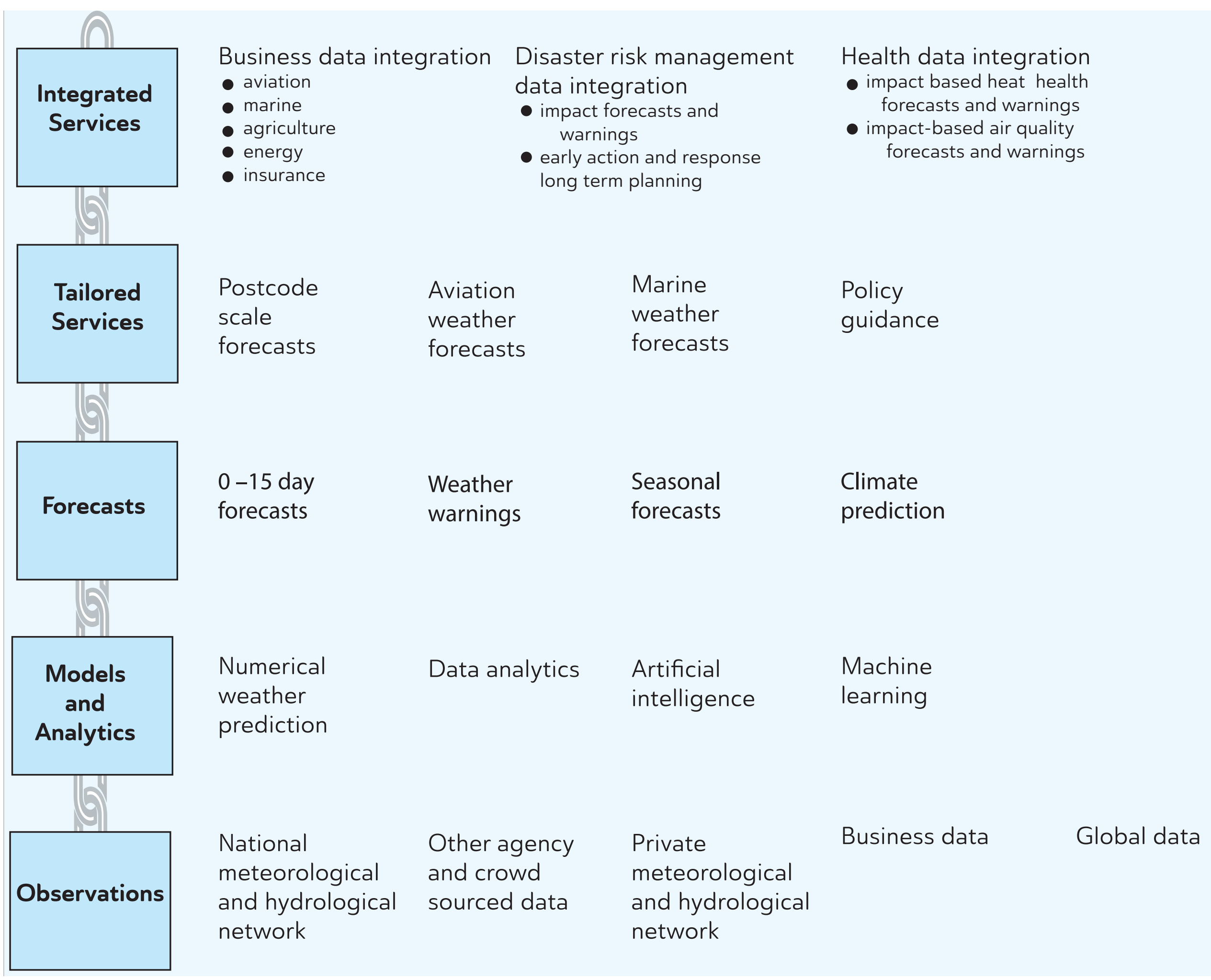


Figure 2 provides examples of activities that fall within the scope of each link in the value chain. Value creation is clearly a feature of the weather value chain, and it is important to establish that weather data are of high value. Indeed, it is at the heart of a recent and relevant regulatory intervention by the European Union (EU). High-value datasets can be defined as data, the reuse of which is associated with important benefits for the society and economy. Public sector data should be subject to a separate set of rules ensuring their availability free of charge, in machine readable formats, provided via application programming interfaces (APIs) and, where relevant, as bulk download—an interpretation based on *EU Open Data Directive 2019*.[11] Meteorological data are clearly of high value using this definition and are recognized as such by the EU.

Economists are discussing whether a beneficial macroeconomic framework is to transition from a viewpoint of value extraction by shareholders—which has been a major driver of the structure of business as well as of national economic policies—toward one of value creation for and by stakeholders[12] (Mazzucato 2018). Considering the meteorological value chain, such a transition would fit well with the underlying characteristics of the global weather enterprise (GWE). In essence, meteorological value is inherently and fundamentally produced collectively—or coproduced.[13]

Figure 2: Examples of the activities that contribute to each link in the weather value chain.



Measuring value

A key question that naturally arises from a value-based perspective of the weather enterprise is how value is assessed. Many economic theories abound regarding value and its assessment, and these have radically changed over time (Carney 2021). Following arguments developed by Mazzucato (2018) and Carney (2021), the intrinsic or inherent value or utility should be assessed; in the case of weather information this relates to the societal benefits of that information, for example, in saving lives and enhancing sustainability such as by avoiding costs from unforeseen weather and climate hazards as well as in stimulating the economy.

Consequently, we argue that the value of weather information needs to be measured as social, socioeconomic, and economic[7] benefits in different ways such as qualitative, quantitative, financial, and social. Each link in the value chain (Figure 2) creates value and that could, in principle, be measured as an activity-based evaluation. On the other hand, the value added by an organization to the whole value chain could be aggregated from a set of activities carried out. Equally, the value created by a country or a region could also be combined into a total value, and then for the world. For each of these categories, the evaluation should concentrate on the social, socioeconomic, and economic benefits produced. However, some of these assessments are not easy to carry out.

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At the activity level, in some respects, the nature of the global weather enterprise means that there are tools available for this purpose. For example, various methods by which the impact of a set of observations—perhaps corresponding to an observation type—on NWP predictive skill can be quantitatively evaluated such as by carrying out observation system experiments or forecast sensitivity to observation calculations. And the WMO uses such assessments as well as expert and user judgement in creating its OSCAR database[14] of the observations required for skilful NWP to be carried out. This forms an input to defining the essential dataset envisaged in the WMO Resolution 40.[15] Kull et al. (2021) provide an assessment of the value of surface-based observations.

The accuracy and reliability or skill of operational NWP predictions are routinely measured quantitatively by major producing centres comparing the predictions with what actually happened. Consequently, any scientific advances that are introduced into the prediction system can be assessed for how much additional skill they produce. Another example of assessing value might be associated with a meteorological instrument manufacturer who adds value by development and manufacture of a new instrument to measure a meteorological variable. In this case, the instrument will need to demonstrate the quality of the measurement via its accuracy, signal-to-noise for instance. Evaluations of NWP or instrumental data quality could be measures of added value although they do not explicitly measure downstream user benefits.

The full value would only arise once the utility of a particular innovation is demonstrated; for example, how useful is a particular increase in NWP skill in producing better weather forecasts of tropical cyclone landfall that will save lives? In other words, while the skill of a numerical weather prediction can be quantitatively assessed, there may not be a simple relationship to the full value of that particular forecast. This is because the utility of a given forecast depends strongly on the use to which it is put. Relatively low skill weather predictions could also have great value.

Role of organizations in creating value

In the private sector, a key element for a company in marketing is to create a value proposition[16] that describes the benefits, both tangible and intangible, that a customer gains from a product or service. Successful companies with clear value propositions may therefore be well placed to assess their overall value creation. However, a particular issue in this regard concerns public sector bodies, such as national meteorological services and universities. As discussed by Mazzucato (2018), most economists and national economic policies do not take explicit account of value being created by public institutions for example, in estimating a country's gross domestic product (GDP). This aspect of GDP estimation has important ramifications for the global weather enterprise. For example, the contribution of R&D by the private sector is typically classified as contributing to production, so adds to GDP but government R&D does not. Not capturing the production value of government is not conducive, in part, because the government itself and society underestimate its intrinsic value. This may lead to faulty investment strategies, such as underfunding of the NMHS observational infrastructure. Significant evidence supports that government spending on meteorological services adds value to the economy.[17] This is derived by: (i) using forecasts and early warnings to mitigate the impact of meteorological and hydrological hazards; (ii) actively encouraging and facilitating companies to use NMHSs' public data; (iii) stimulating the national economy through research and development in universities and NMHSs; and (iv) ensuring sufficient state funding is allocated to NMHSs to carry out their public task. Therefore, governments are key engines of growth in the value creation process.

It is recognized by many governments that a role of the state is to enable companies to be successful so that they can create value; this enabling function of the public sector can take several different forms such as the production of public research and data that the private sector can use. But this enabling function can be seen by governments as incurring a cost rather than being recognized as value creation in itself. If instead, governments explicitly measured the utilization by the private sector of public data and models for example, produced by national meteorological services, they would benefit considerably. These could include providing: (i) an incentive for NMHSs to actively encourage and facilitate companies to use public data; (ii) a more comprehensive understanding and quantification of the role of NMHSs and universities in stimulating the national economy; and (iii) evidence for the level of state funding to be allocated to public institutions. Such examples underline the benefits of the positive ripple effect throughout the value chain of value created at one point; in other words, by taking a holistic view of the value chain.

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A related issue is that for a commercial activity, a key factor is the determination of a fair price for goods and services. It is probably accurate to say that existing market conditions operate closer to price determining value rather than value determining price. And in such conditions price depends on the extent of competitive pressure to reduce prices as well as a judgement by users of what constitutes a fair and affordable price. However, if in essence it is price that determines value, the potential exists to underestimate the value of the weather enterprise hugely because of the large benefits contributing to social value and the significant role of government in value creation.

In conclusion, measuring value can be difficult, not least because it has elements that must be qualitative and subjective, while other aspects can be quantitatively and even scientifically assessed. Nonetheless, despite such difficulties, recognizing value creation explicitly either by qualitative or quantitative means is an important way to build trust and establish more clarity.

Public, private, and academic producers

Accepting the critical nature of meteorological globalization, national policies and market structures need to recognize global interdependencies.

The roles and responsibilities of the many public, private, and academic producers of meteorological value vary significantly dependent on how they are interpreted in different countries. Value is created at each step in the weather value chain and all the three sectors can, and do, generate value at each step. The economic questions are: how are producers financed, and how do they operate best to create value? Accepting the critical nature of meteorological globalization, national policies and market structures need to recognize global interdependencies. National and international aspects of the global weather enterprise have the potential to collide detrimentally or to re-enforce each other for collective benefit.

We touch on only those aspects that relate to the issue of how value is added, and do not specifically discuss whether certain roles and responsibilities should be reserved for or prohibited or discouraged to either public, private, or academic providers. Indeed, it could be argued that essentially no roles or responsibilities exist that are, in principle, beyond the scope of any actor in the weather enterprise whether they be in the public, private, or academic domains. National governmental policies are diverse but may try to provide some clarity on these roles and responsibilities. However, in conclusion, actors from the public, private, and academic sectors each create value for society and the economy. Neither can value be created by one sector at the expense of the other, nor be left exclusively to the private sector while the government is concerned only with market failures and regulation. In effect, the market must be well managed to maximize value to society as a whole by enabling all providers to the enterprise the best opportunity to create value.

Risks and rewards

Central to creating value in the GWE is the process of innovation and a clear understanding of the roles of various actors in that process. It is important to understand where risk is taken and where the rewards go. Mazzucato (2015) notes that innovation often relies on investments by the state if individuals or companies are unable to fund this because of the high degree of risk involved. Governments fund research and training in academia with a goal of stimulating new and existing companies to exploit the knowledge created. Academia can collaborate with companies to carry out this translation. Also, companies can cooperate with each other via research consortia and via user–producer interactions in product and service development. Put in the context of the weather enterprise, the state or a collection of states take the risk of innovation uncertainty in the development of numerical weather prediction, satellite observing systems, and related advanced technologies, such as the Internet. These activities are the result of long-term cumulative, collective, and uncertain processes. Single states take on the responsibility for their weather, climate, and hydrological observation networks that underwrite the ability of business to innovate in the weather enterprise because they incur significant fixed costs that individual companies are unlikely to support.

However, it is not clear that a state always receives its fair share from the global and national rewards that accrue to certain actors who position themselves along the cumulative innovation curve where the weather enterprise generates financial returns.[18] This argument may extend to social benefit, where larger states reap the rewards of access to observations produced in and by less developed regions to improve their own weather warnings; the states in those developing regions may not be willing or financially able to continue their support for infrastructure and innovation. Conversely, smaller states can benefit from global and larger states' investments—in satellites, NWP, research and development—even though they themselves may not be contributing much to global value creation.

Clearly, companies also take on significant risks in creating value. An example would be the situation where companies invest in developing and owning their own satellite constellation[19] with a business model that provides a data service to users. In this case, the risk of a failure of a satellite at launch or in orbit is borne by the company directly rather than by the user. In contrast, government space agencies will often contract companies to build and launch satellites, but the risk of failure is then typically borne by the public sector. In all the cases discussed it is important to recognize explicitly the value of risk taking by both public and private sector organizations.

Misunderstanding of these issues has led to some misconceptions as well as myths of how the sectors regard the role of the others. For example, some actors, including some companies, may regard public institutions as being inherently inefficient and not innovative. Equally, it is not uncommon for companies to be viewed by public organizations as fundamentally motivated by wealth extraction for and by shareholders as opposed to value creation, where that value benefits society widely.

A general principle that could inform financing and operational questions is that all actors in the global weather enterprise need to be treated equitably so that they can maximize the value they can create for the enterprise. Ensuring value maximization in part translates to removing, as far as possible, any barriers or obstacles to value creation. In a global market in which public, private, and academic sectors all participate, this often requires ensuring that competition between producers, where it occurs, must be fair and seen to be fair.

Because of meteorological globalization, all producers depend on each other, either implicitly or explicitly and to a lesser or greater extent, to enable each of them to maximize their own value creation potential. In other words, at a sectorwide level, there is self-interest and benefit by enabling other sectors to thrive. To provide a concrete example, it is in the interest of a private company supplying tailored weather services to businesses that the national meteorological service—which has the responsibility to support the collection and supply of meteorological observations—is well financed by governments to do so. In essence, the private sector needs to be advocates for investment in the public and academic sector component of the weather enterprise. Conversely, the existence of successful private companies that add value to information produced by the public sector—such as long-term research or public weather forecasts—needs to be a measure used by governments to evaluate the socioeconomic benefits of investment in, and not seen as a cost of, the public sector. In conclusion, in looking to create value, actors in each sector should examine their own processes to see how they benefit from the activities of others.

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Data sharing and exchange

In meteorology and elsewhere, issues of value often revolve around the conditions including price, under which data are made available to users of that data such as observations, predictions, forecasts, and information services. Many categories of weather data are commonly referred to and it is helpful to summarize some of their characteristics.

- ***Open data –*** Public data that are universally available free at the point of use or at a cost to the user no greater than that incurred by the provider to retrieve the data. These data are usually regarded as having high value.
- ***Public data –*** Data of all kinds that are owned by public institutions. The data may or may not be produced by a public or a private organization but are funded from the public purse.
- ***High value data –*** A category of public data, used by the European Union, which are vital for the socioeconomic wellbeing of its citizens. Meteorological data are included in this category; however, it is unclear whether this means that all meteorological data are considered of high value or only a defined subset.
- ***Private data –*** Data of all kinds that are owned by commercial organizations. The data may or may not be funded from the public purse. They may be of high value and therefore the public task may benefit by using private data. They can also be referred to as commercial or proprietary data.
- ***Public task –*** Meteorological tasks mandated by governments, sometimes via legislation, carried out by specified organizations that may or may not be the national meteorological service. In many countries these tasks include issuing public weather warnings and providing weather information to inform national security issues, but they may include other functions such as ensuring a suitable national meteorological observing system is in place and functional. Organizations that deliver the public task may—or may not depending on their governance—also deliver other tasks that do not fall in this category.
- ***Essential data –*** WMO Resolution 40 refers to essential data as being those meteorological data that are required to deliver public tasks, which might include some private data.
- ***Additional data –*** WMO Resolution 40 refers to additional data as those data that are not required to deliver public tasks. Some additional data, although in the category of public data, are made available on commercial terms.

It should be noted that countries differ significantly in the extent to which public data are treated as open—and essentially free at the point of use—compared to charging a commercial rate for some or even most of the public data[20] (Rogers and Tsirkunov 2021; Rogers et al. 2021).

Confusion and mistrust can arise if users—who employ open public data that are essentially free for them to use—also seek to obtain proprietary data or additional public data for which a commercial rate is charged, and find that they are required to pay for those data. It is sometimes said that all meteorological data are, or should be, open data and so no meteorological data should incur a cost to the user. This is a misreading of how value is created within the weather enterprise and as defined in the data categories provided in this technical note. Clearly all data incur a cost in their production. Those costs are either borne by government funds or by companies and their customers. In the case of some governments, these costs are implicitly seen as being covered by the return from economic activity generated from the data across the value chain in the form of private sector employment, corporate taxes and so on, and importantly, via the avoided costs of deleterious impacts of hazardous weather events by using high value weather information. In the case of companies, either governments on behalf of users or the users or customers themselves are the only ways for companies to cover the costs of providing their data. Following the arguments discussed in this technical note, the prices charged by companies should be strongly determined by the value of the data. Inherently, companies need to build in a profit element as they need to invest themselves in research and development of new products and services. However, if a provider is in a near monopoly position then fair pricing can be an issue to be resolved. Equally, governments that fund data provision implicitly expect sufficient return that turns a cost into an investment. This enables governments to use the excess public financial returns generated from high value meteorological data to invest in the economy. Part of that investment will be, for example, in research and development in universities and national meteorological services, but also may contribute to green infrastructure.

A goal is to enable more observations to be available including for operational NWP (Kull et al. 2021). As well as a comprehensive description of the ecosystem encompassing all types of existing observations and known data gaps, it is important to establish a better understanding of the mixed economy that underpins financial resources. In addition, the development of new observational techniques needs to be fully supported. Improved functioning of the global weather enterprise ecosystem would be greatly facilitated by removing obstacles to making withheld data widely available; providing incentives to fill data gaps;[21] establishing a level playing field for data exchange of both public and private data sources; and enabling new technology to be fast tracked so that more and better observations can be available more rapidly. These developments require trusting and meaningful engagement and partnership between the public, private, and academic sectors comprising the GWE. These relationships need to recognize the value that each participating organization brings to the endeavor.

As well as a comprehensive description of the ecosystem encompassing all types of existing observations and known data gaps, it is important to establish a better understanding of the mixed economy that underpins financial resources.

Free riding and rent seeking

Within economics, it is recognized that markets can exhibit undesirable attributes and two of these are free riding and rent seeking.

The economic concept of free riding for the GWE can sometimes be articulated with the following narrative: companies—particularly large ones with an international reach—that use open public weather data to create profit while at the same time, neither invest in the infrastructure, such as the global observing system that generates the public data, nor make their proprietary data available without cost or restrictions. This narrative has significant flaws. It fails to recognize the benefits companies bring by using public weather data to create high value user services, and create jobs and economic opportunities locally. The economic activity created by companies adds to the funds that governments use to finance the provision of the public weather data. So, they do invest, although indirectly, to national economies and hence, in that meteorological infrastructure. Also, to address the second point regarding charging for proprietary data, the business model of companies relies on data sales and so they would simply be bankrupt without this revenue.

Where free riding can perhaps seem most apposite is if the companies in question are not indigenous, and employ people and pay taxes in other countries from the one that funds public open data. From a national perspective this could be viewed as a highly disadvantageous situation. But even in this case there are ameliorating factors. Perhaps the primary factor arises because of the global nature of weather and climate. Government investments in the meteorological infrastructure are a contribution to a global system such as that for observations. So, the fact that nonindigenous companies are providing indirect economic benefits to another country helps, in principle, to enable the government of that other country to support the global infrastructure and this is of benefit to all in varying degrees. In addition, high value user services produced by a company do not depend on the physical presence of the company in the country. Such services will often be available to users in other countries and thus have either some societal or economic or both benefits there— developing countries often rely on this, for example. In any case, public data distribution incurs only a marginal cost, and companies that are sometimes characterized as free riders do not create additional variable costs to open data providers.

Rent seeking is the attempt to create wealth without adding value. Adam Smith's concept of a free market in "The Wealth of Nations" (Smith 1776) is a market free from rent seeking. Arguably, for meteorology, rent seeking does not seem to be prevalent; however, the perception of rent seeking may exist. In essence, this comes down to how much added value a particular organization may create. For a large national meteorological service that produces a wide range of value—via making and curating observations and creating NWP prediction data, for example—the added value that a small company that uses free access to such NWP data and then packages that data attractively for users to buy an app service may be thought of as being sufficiently small, is regarded as close to rentier activity.

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Another possible suspicion of rent seeking might arise from the sale of the same data multiple times to different customers. Once the investment has been made to produce the data, selling it to an additional customer may come at low cost to the producer. Rent seeking would apply if the creation of the data was carried out by a different organization to the one that sells the data to multiple customers; the latter company has not added any value. Selling a data service is commonplace—as in music streaming—and has been questioned in these terms. Users, on the other hand, care mostly about the benefits they derive from using the data and in many circumstances that is largely independent of how many other users access that data.

These are difficult waters to navigate and can and do create mistrust in the global weather enterprise. However, it is important to discuss these issues openly so that an approach can be codeveloped that enables all actors to thrive in this collective enterprise.

Competition, cooperation, and coproduction

Many of the issues discussed impact how organizations that deliver meteorological value relate to each other. These relationships can be seen through various lenses. One is whether organizations are in competition with each other—this being the normal situation within a market comprising companies and seen as advantageous to the market in the creation of value. In the global weather enterprise, competition is also possible between public organizations and companies to provide commercial data services. On the other hand, there are relationships that are noncompetitive, and so embrace cooperation, collaboration, and coproduction or partnership.

Competition between public and private organizations to sell weather information commercially warrants careful consideration. Some national meteorological services act in a commercial fashion to a greater or lesser extent. The report by the World Bank (2019) on *The Power of Partnership*[17] (PoP) provides an analysis of the impact of such competition in various countries. The report suggests that if public institutions engage in commercial activity, this might distort the market by stifling or crowding out the private sector component of the weather enterprise in that country. In such circumstances, the report proposes that an independent national regulator should exist to monitor the implementation of a level playing field (Rogers et al. 2021). However, this does not imply that the government must be a bystander in the value creation process. For example, Polanyi (1944) argues that the government does not distort the market but rather creates it, and in doing so, it must abide by its rules.

In some countries legislation enacted governs how such competition should be carried out. For example, in the UK the Competition Act of 1998[22] states: "… where public bodies do engage in economic activities, a level playing field and a similar commitment to compliance exists for all operators in those markets, particularly in mixed markets in which public bodies, private firms and third sector organisations (for example, charities) compete alongside one another. Effective competition in those markets can benefit the wider economy by encouraging greater productivity and innovation and preserving long term growth, while continuing to provide greater value for money to the taxpayer." Consequently, comes a requirement for a level playing field such that no cross subsidies exist within the public body that would create unfair competition. This requirement applies to national meteorological services that engage in commercial activities. Various approaches have been employed, such as creating a wholly owned subsidiary company or publishing annual accounts that provide separate ledgers for the commercial component. The PoP report[17] suggests that nonetheless, the perception of a nonlevel playing field could be enough to stifle the private sector entering the market.

Effective competition in those markets can benefit the wider economy by encouraging greater productivity and innovation and preserving long term growth, while continuing to provide greater value for money to the taxpayer.

Cooperation between the public, private, and academic sectors is advantageous in creating value. Some economies, particularly those with highly developed meteorological infrastructure, have experienced many examples of productive collaboration between scientists in national meteorological services and those in universities. These relationships can be productive because each side has something to gain—the academic gains access to an operational weather prediction system that creates significant historical datasets of value for research and the NMHS scientist can tap into the longer term research themes typical of academia. Coproduction in this context would occur where researchers from both sides combine forces to produce for instance, a new physical parametrization scheme for the operational NWP model. An even more profound relationship that one could characterize as a partnership, might involve both parties relying on the other for delivery of a part of their own strategy.

Such relationships between a national meteorological service and a private sector company are rarer but not unknown. Recent examples might be in computing and machine learning. A general question arises when the public and private sectors are both active in the same area. Does competition or noncompetitive collaboration lead to more accumulated added value? A particular example is in the provision of observational data. The observational data ecosystem includes: (i) weather observations made by public, private, and academic organizations worldwide; (ii) international sharing of observational data with the aim of all who need the data having access; and (iii) the meteorological global telecommunications system[23] that provides the infrastructure for international public data exchange. This ecosystem functions relatively well today but is not perfect, as witness for example, known data gaps and withheld data, making the issue of competition versus cooperation a live one.

In conclusion, unfair competition or even the perception of unfair competition between organizations in different sectors would be, and probably is, a major source of mistrust and inefficiencies in the GWE. In contrast, fair and transparent competition between organizations within a given sector is generally seen positively although there are also mutual benefits in cooperation and collaboration. It is in the mutual self-interest of all three sectors to be advocates for investment across all sectors based on clarity regarding the added value that each actor creates.

National regulations

The relationships between organizations operating within the public, private, and academic sectors are strongly influenced by any government-level interventions, such as establishing and enforcing competition laws, an independent regulator, or even a meteorological law (Rogers et al. 2021). The governance of national meteorological services may also establish clear operating principles under which commercial activity could or should be undertaken. A wide variety of what could be referred to as regulations of national weather markets exist across the globe. This diversity is understandable but it presents a challenge for organizations, public and private, that operate across national boundaries. Examination of the structure of the weather market in various countries, such as in the PoP report,[17] shows that those countries where a clear legislative framework defines the expected operating principles are among those that have established the most successful national weather enterprises.

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Conclusions

The concept of value is about the utility or benefit of goods, data, or services to whomever uses them. Value creation is a defining feature of the global weather enterprise. A consequence of viewing the GWE through a value lens is that value needs to be assessed so that, for example, the price for charged data or services can be determined by their value, governments can better understand the value created by the entire enterprise, and markets can be designed to maximize value creation.

Meteorological value is inherently and fundamentally collectively produced, or coproduced, by all the organizations and individuals across the public, private, and academic sectors worldwide that contribute added value. In such an intrinsically collective endeavor it is important for all actors to understand the interdependencies. Governments play a key role both as investors in the GWE and also in structuring national market conditions to ensure it generates maximum value. This needs to include legislative and regulatory controls as well as recognition in national accounts of the measured added value that is being generated by all actors in the enterprise. Taking a holistic national view is important so that national meteorological ecosystems can be optimized for value creation. Issues such as ensuring a level playing field for competition and provision of incentives to promote collaboration or partnership to enhance innovation are crucial. Furthermore, the part that countries play in contributing to the global interdependent effort to create value for the benefit of all citizens is critical, and this is facilitated by the WMO, the World Bank, the IPCC, trade associations, and other international institutions and mechanisms. In an increasingly interdependent world, it is the interface between organizations, sectors, and countries that lie at the heart of further optimization of the weather enterprise. In short, national, and global considerations must go forward hand in hand; noting that significant differences arise in the way the value chain operates for instance, between developed and developing countries, and this can lead to diversity in incentive structures.

As a driver for the weather enterprise, incentives are essential for the benefits of embedding value creation to be fully realized for example, for actors from the public, private, and academic sectors to cooperate more extensively. Clearly governments play a key role in creating such incentives and in this technical note, we have identified several ways in which this might happen. For governments, the incentive to develop and improve their national meteorological ecosystem revolve around the social, socioeconomic, and economic benefits of the weather enterprise. The value of weather information to protect citizens and the economy become more apparent because citizens and businesses are increasingly vulnerable to natural hazards particularly as climate changes. Consequently, these benefits become more tangible as mitigation of the impacts of hazards becomes an imperative.

While it is important to invest in the meteorological infrastructure, we would argue that it is also as important to address issues—such as design of market structures conducive for value creation, enhancing legislative and regulatory frameworks—and account for value creation in both public, private, and academic sectors. Growth in the global meteorological ecosystem, resulting from increased value creation throughout the value chain, is highly likely to be beneficial for all actors. Specific examples of possible interventions aimed at maximizing value creation in the weather enterprise are summarized in Box 1.

Establishing a shared understanding of how meteorological value is created, who creates it, and how it should be taken into account is a route to even greater future success.

In conclusion, the global weather enterprise has developed into a highly successful and internationally interconnected endeavor. Establishing a shared understanding of how meteorological value is created, who creates it, and how it should be taken into account is a route to even greater future success by enhancing clarity and trust within the enterprise.

Acknowledgments

The authors would like to thank Vladimir Tsirkunov and Makoto Suwa of the World Bank Group for valuable comments on an earlier draft of this technical note, and Daniel Kull, Jack Hayes, and Lindsey Jones for insightful reviews. They would also like to thank their guests on The WeatherPod podcast[24] and colleagues in the Global Weather Enterprise Forum who have shared their perspectives that have helped shape the ideas expressed in this technical note.

Box 1: Specific examples of interventions to maximize value creation in the weather enterprise

For all actors:

- Integrate value creation as an explicit aspect of mission and strategy.
- Analyze interdependencies implied by meteorological globalization.
- Assess their contributions to value creation to guide investment decisions.

For governments:

- Structure market conditions to ensure national meteorological ecosystems are optimized for value creation, including enacting national legislative and regulatory controls for meteorology, and provision of clear and transparent governance for the NMHS describing roles and responsibilities.
- In national accounts, include explicitly the value created by public institutions such as universities, research centres and the NMHS.
- Guide appropriate investment levels in the NMHS and academia, take account of all aspects of value creation including stimulation of the private sector resulting from the creation of public data and services.

For NMHSs:

- Make all public data open and free at the point of use to maximize their value.
- Establish a clear and audited separation of concerns for commercial and noncommercial activities including publishing separate transparent accounts to demonstrate the absence of cross subsidies.
- Determine whether competition, cooperation, or partnership create maximum value for the national enterprise when considering taking on new activities.

For companies:

- Make the case for public investment in academia and NMHSs as a fundamental enabler of value creation by the private sector.
- Be alert to (so as to avoid) the possibility of perceptions of free riding and rent seeking.
- Proactively consider cooperating or partnering with either the public sector or academia or both entities as a way to maximize value creation for stakeholders and returns for investors.

For academia:

- Enable the potential value created by research (the impact) to be realized.
- Explore opportunities for partnership with NMHSs and companies as a way to maximize value creation and the impact of research.
- Build costs into funding proposals to obtain data (from whichever source) that are required inputs for research projects.

For international and donor organizations:

- Promote the maximization of value creation throughout the value chain as a guiding principle in strategic decision making such as investments.
- Encourage public–private–academic sector cooperation to maximize value creation.
- Support the development of international resources available within the global weather enterprise and promote their exploitation in designing national programs.

Notes

1. Herein the words "information", "data", "products", and "services" are used interchangeably although clearly certain characteristics differentiate these terms.

2. The Global Weather Enterprise (GWE) is the value chain of activities of the public, private, and academic sectors providing accurate, reliable, and timely weather and climate related information. It contributes to the safety of life and property, poverty reduction, and the promotion of economic development (confer, see the Sustainable Development Goals and Agenda 2030).

3. https://library.wmo.int/index.php?lvl=notice_display&id=21763#.YBai2Tlxc2w

4. The notion of a global framework has existed for a long time—for example, the International Meteorological Organization was created in 1873 and superseded by the WMO in 1950. The nature of the framework has evolved over the years because of scientific and technological advances and, more recently, with the development of broader public–private engagement.

5. These global aspects may be hidden to an end user, for example of a weather app, but is nonetheless a reality.

6. In this technical note, we use the word "data" in a wide sense to mean weather observations, predictions, forecasts, and information services.

7. Here the word "social" refers to noneconomic benefits, socioeconomic being the social benefits accruing from the added economic activity, and economic is the direct monetary benefit. Since social value is derived from the combination of private and external benefits, it is large because of the significant external benefits resulting from the widespread use of weather information across the entire economy.

8. c.f., Porter, 1985. See by way of comparison "*Competitive Advantage: Creating and Sustaining Superior Performance*", The Free Press, Macmillan, Inc., New York.

9. https://public.wmo.int/en/programmes/global-observing-system

10. Examples of public data integration include forecasts of wildfire risk, flooding, and health impacts of air pollution events. Typically, such services are codeveloped by several public agencies.

11. https://eur-lex.europa.eu/legal-content/EN/TXT/?qid=1561563110433&uri=CELEX:32019L1024

12. https://downloads.bbc.co.uk/radio4/reith2020/Reith_2020_Lecture_1_transcript.pdf

13. Alternatively referred to as co-developed.

14. http://www.wmo-sat.info/oscar/

15. https://library.wmo.int/index.php?lvl=notice_display&id=21657#.X-3vDTRxc2w

16. https://www.mckinsey.com/business-functions/strategy-and-corporate-finance/our-insights/delivering-value-to-customers

17. c.f. see, *The Power of Partnership: Public and Private Engagement in Hydromet Services.* The World Bank, 2019. Available from: https://www.gfdrr.org/en/power-of-partnership

18. A response to perceptions of a lack of "just return" to governments is sometimes seen in an increased demand to charge for previously freely available public data—as seen in some developing country NHMS's seeking to recoup some of the cost of maintaining observational networks.

19. See for example the Spire Global satellite constellation, https://spire.com/

20. See the report in December 2017: "*Weather Permitting: Review of open access to weather data in New Zealand*" for further information comparing several countries (Norway, UK, USA, New Zealand, Australia, and France) regarding their treatment of public data: https://www.mbie.govt.nz/science-and-technology/science-and-innovation/research-and-data/open-access-to-weather-data-review/

21. It is important to recognize the crucial value of both observations for initializing numerical weather predictions in real time as well as in situ local observations used for validation of the forecasts to isolate and improve on deficiencies in prediction models. National observing networks, including in developing countries, remain a critical requirement even in the satellite era.

22. https://www.legislation.gov.uk/ukpga/1998/41/contents

23. https://public.wmo.int/en/programmes/global-telecommunication-system

24. https://www.gweforum.org/series/podcasts/

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