The Epistemic Privilege of Measurement: Motivating a Functionalist Account

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Philosophers and metrologists have refuted the view that measurement's epistemic privilege in scientific practice is explained by its theory-neutrality. Rather, they now explicitly appeal to the role that theories play in measurement. I formulate a challenge for this view: scientists sometimes ascribe epistemic privilege to measurements even if they lack a shared theory about their target quantity, which I illustrate through a case study from early geodesy. Drawing on that case, I argue that the epistemic privilege of measurement precedes shared background theory and is better explained by its pre-theoretic function in enabling a distinctive kind of inquiry.

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1. Introduction

Theoretical interest in measurement has long been driven by the view that measurement operations provide abstract concepts with theory-neutral meaning and evidence (Bridgman 1927; Campbell 1928). This situation changed quite drastically over the last decades. The role of theory in measurement has been one, if not *the* dominant theme in recent metrological and philosophical work on the subject. Identifying which inferences qualify as measurements, we are told, is "theory-dependent" (van Fraassen 2012; Giordani and Mari 2021), as is the separation between confounding factors and the correct magnitude of a quantity under measurement (Tal 2019). While this work has led to a better understanding of measurement practice, it almost exclusively draws from examples in contemporary metrology. As a consequence, our existing view on measurement is overwhelmingly based on studies of long-established measures within securely established theoretical frameworks (e.g. Tal 2016; Mari et al. 2017).

One of the key questions that theory-dependent accounts of measurements have to answer is why measurement is assigned a special epistemic status in scientific practice – a privilege that has traditionally been linked to its theory-neutrality (Bridgman 1927; Campbell 1928). Throughout the last decade, the Italian metrologists Luca Mari, Paolo Carbone, Alessandro Giordani, and Dario Petri have worked out a 'theory-laden' epistemology of measurement to fulfill that warrant. In their *structural* account, the epistemic status of measurements is explained by scientists' agreement on general theoretical assumptions, which allows for "intersubjective", i.e., contextually invariant inferences (Mari et al. 2017, 55). In what follows, I identify a challenge for that account: measurements can be pursued in the absence of agreement on a general theory. I motivate that challenge based on a case study on the measurement of the earth's figure in early physical geodesy. Geodesists did not have recourse to a shared general theory of their target quantity, from which I conclude that the structural account systematically *overestimates* the role of theory in measurement. While my ostensive target is Mari et. al.'s account, I provide some reasons that my argument also applies to similar proposals put forward by Eran Tal and Bas van Fraassen.

In response to the problems faced by the structural account, I propose that measurement's special status results from the specific commitments held by measurement agents and their *function* in enabling a distinctive kind of inquiry. I refer to these as *stability* and *nomicity commitments*, referring to agents' commitment to establishing the stability of outcomes under similar conditions and the lawfulness of their variation across conditions.

2. The Epistemic Privilege of Measurement

Measurement is generally assigned a privileged role in scientific practice. The *outcomes* of measurement inferences are taken to (at least loosely) constrain new theorizing. This is not an observation about the facts explaining the epistemic status of a particular measurement, but the general importance that is attributed to measurement as a *practice*. Recent work in the philosophy has rejected traditional views that linked this privilege to measurement's theory-neutrality (Bridgman 1927; Campbell 1928). This rejection is motivated by two related observations on the theory-dependence of measurement. The first observation concerns the fact that sophisticated measurement procedures rely on theoretical characterizations of the nomic link between *measurement indicators* and a quantitative *measurement outcome* (van Fraassen 2012; Tal 2019; Giordani and Mari 2021). The second observations concern the fact that scientists often ascribe high reliability to measurement outcomes if several mutually coherent theories are involved in the measurement process. Most notably, all our basic units in the S.I. system have been redefined in terms of interlinked theoretical constants (de Courtenay 2021).

Since these two observations undermine theory-neutrality, advocates of theory-dependence need to offer an alternative explanation of measurement's epistemic privilege. The most sophisticated explanation of that sort is offered by the Italian metrologists Luca Mari, Paolo Carbone, Alessandro Giordani, and Dario Petri. Their "structural interpretation" asserts that measurement is best understood as a tripartite *inferential activity*, whose structure individuates it from other forms of inference and empirical assessment. This claim is supported by the observations that contemporary measurements combine controlled manipulations of measurement indications with several different levels of theoretical framing: (i) a general theoretical model of the target property (ii) a specific theoretical model of its instantiation in a particular object, and (iii) a theoretical model of how that object is nomically connected to measurement instruments.

Model Type	**Description**
General Model	Quantitative theoretical description of **target property** in terms of **other quantities**, using **general theoretical laws**
Specific Model	Quantitative description of an **instantiation of that property** in one or multiple **specific objects of interest**
Model of Measurement Process	Description of the interaction between the **specific model's parameters** and one or many **measurement instruments,** theoretically identifying and anticipating **possible sources of error** and (potentially) **quantifying uncertainty**

Fig. 1. Illustration of Mari et. al's structural interpretation of measurement.

These models in conjunction are used to complete a holistic measurement task: determining the magnitude of a particular instance of a target property. The structural interpretation explains the epistemic privilege of measurement in virtue of the sophisticated structure of this inferential process. The abstraction of the general model – usually rooted in theories with astonishing empirical scope – allows scientists to define a unit that transcends local context, guaranteeing "*subject-independence*". The employment specific and measurement process models, in turn, facilitate a measurement's sensitivity to the particular instantiation of the quantity in question – guaranteeing *"object-orientedness"* (Mari et al. 2017, 65). In jointly fulfilling these two criteria, measurement is individuated from other forms of assessment such as observation, simulation, or theoretical explanation.

In what follows, I will focus on the structural interpretation when discussing the epistemic privilege of theory-dependent measurement. In some sense, this is an undetermined choice, which I justify by the fact that Mari et. al.'s offers the most detailed account of the inferential structure measurement. Since this structure is the explanans of measurement's epistemic privilege, I take the structural explanation to be the *strongest* explanation. My focus is further justified by the observation that other explanations bear close similarities to their arguments. For example, Eran Tal argues that measurement's objectivity is a result of its *robustness*, where the latter is guaranteed by metrologists successfully linking an abstract theoretical model of a quantity to local modeling assumptions about specific measurement processes (Tal 2017). Bas van Fraassen, similarly, argues that measurements uniquely fulfill their privileged function in "empirically grounding" an abstract quantity in virtue of the general theoretical assumptions about what counts as a measurement of that quantity and specific assumptions about how confounding distortions can be predicted (van Fraassen 2012).

2. Measuring planetary figures in early geodesy

In the previous sections, I have outlined how metrologists and philosophers explain the epistemic privilege of measurements, focussing particularly on Mari et. al's *structural interpretation*. In what follows, I investigate a historical case study in which a crucial aspect of their explanation is not realized – namely, a shared general theoretical framework to characterize the target quantity. The historical case is offered by early geodetic measurements of the earth's ellipticity, the defining quantity of the earth's general figure. These measurements began after scientists had observed that surface gravity and curvature vary with latitude, indicating that the earth might not be a sphere. In response to this, they tried to determine the degree to which the earth deviates from a spherical shape by being prolonged or prolate – a quantity that can be geometrically represented as an ellipsoid's *ellipticity*. The focus of what follows is not on whether early geodesists established a unique value for the earth's ellipticity – which they did not – but on the relationship between general theory and measurement and the kind of inquiry that was possible in the absence of theoretical agreement.

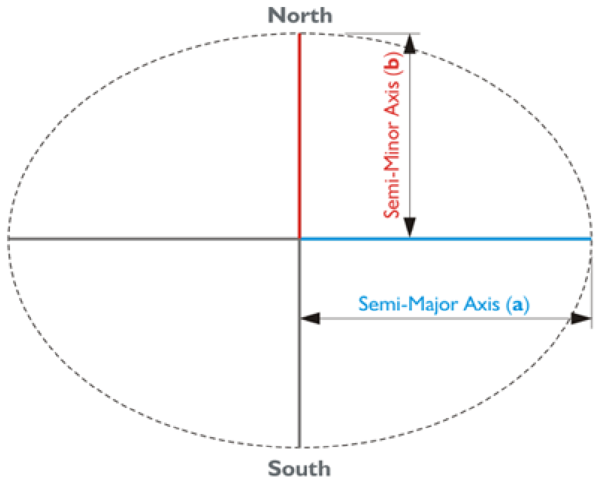

Fig. 2: Meridian ellipse of an ellipsoid of revolution, where *a* and *b* are parameters in terms of which polar flattening ($f = \frac{a-b}{a}$) is defined.

2.1 Newton

In his *Principia*, Isaac Newton proposed a novel theory of planetary figures, from which he derived a first estimate of the ellipticity of the earth. This theory was deeply embedded in his theory of universal gravitation. Since Newton took the theory of gravitation to generalize to the mutual attraction between *all* celestial and terrestrial bodies, he conjectured that the same force that keeps the pendulum swinging isochronously and planets moving in their orbits also holds the key to understanding the earth's physical formation. Establishing *how* universal gravitation could affect the formation of planets formed the core of Newton's novel theory of the earth's figure. Put very roughly, that theory extended reasoning from hydrostatics to dynamic phenomena, by treating the equilibrium state of a rotating fluid as the joint result of its initial motion, its initial density distribution, and a theorized force that acts regularly between all of its constituent particles. Newton concluded that the earth, modeled as a homogenous fluid that rotates with uniform angular velocity, must have the shape of an oblate ellipsoid with an ellipticity of 1/230 to be in a state of hydrostatic equilibrium. Corresponding to the resulting latitudinal variation in the distances between points on the earth's surface and its center, he then predicted the effective surface gravity – indicated by the length of an isochronous seconds-pendulum – to vary as the square of the sine of the latitude (C&W, 828).

Newton supported these claims by citing measurements of the variation of surface gravity conducted by several French physicists in the 1670s. Jean Richer first measured such a variation during an expedition for the Paris Académie. From 1671 to 1673, he had monitored the daily swings of a pendulum clock. While the clock was closely calibrated to astronomical time in Paris, he found it consistently losing 2 1/2 minutes every day in Cayenne (Académie royale des sciences 1703, 1:169). In 1682, Jean Varin, Jean Des Hayes, and Guillaume De Glos replicated this basic result in Gorée (off the west coast of Africa) and Guadaloupe (West Indies) but recorded a different variation with latitude (Académie royale des sciences 1703, 1:357–58).

2.2 Huygens

After reading the first edition of Newton's Principia, Christian Huygens worked out an alternative treatment of the problem, adding new impulses to Newton's results and challenging the empirical support that they provided for universal gravitation. Like many of his contemporaries, he took the idea that all particles of matter attract each other to be absurd, restricting the domain of gravitation to the surface and interior of planets. His work on the matter was published in 1690 as an appendix to his Horologium Oscillatorium, entitled *Discours de la cause de la pesanteur* (Discourse on the cause of gravity). In the problem of the earth figure, Huygens had identified a potential empirical counterexample, which allowed him to level a substantial, empirical attack on universal gravity. Newton's theory would then not only be unintelligible but fail short of explaining one of its explicitly associated phenomena. To show this, Huygens derived the equilibrium figures of fluids subject to alternative gravitational forces and tried to show that they account better for actual measurement outcomes. Huygens concluded that under his alternative law of gravity, the two channels are balanced if the earth's ellipticity is 1/578, implying that the earth is less oblate than Newton had assumed (Huygens 1690, 156).

While Huygens did not provide new empirical arguments *in favor* of his model, he did offer measurement results that seemed to speak *against* Newton's results. Just a few years before writing his *Discourse*, he had come up with a trial for how well his pendulum clocks might aid nautical navigation. In May 1686, the ship *Alcmaer* had embarked on a voyage to the Cape of Good Hope, carrying with it two specifically designed exemplars of Huygens's pendulum clocks. If the pendulum clock should help in finding longitude at sea, it needed to be accompanied theoretical model of the earth's figure and the latitudinal variations in the strength of surface gravity on such a figure. The performance of different models in this task, therefore, offered a test of their accuracy. As Eric Schliesser and George Smith have reconstructed, this test relied on two astronomical determinations of the longitude at the start (Cape of Good Hope) and end (Dutch island of Texel) of the voyage, where the latter was compared with the longitude indicated by the clock on arrival. Huygens was very satisfied with the results. In his report to the directors of the DEIC, he notes that "the total longitude between these two places [has been measured so well] that it only departs by 5 to 6 [nautical] miles, which I admit I have seen with exceptional satisfaction" (Schliesser and Smith 2000, 16).

The accuracy of Huygens's corrections indicated that Newton's predictions would have led to determinations of longitude that are noticeably wrong. These predictions, of course, were derived from the theory of universal gravitation. If all constituent particles of the earth attract each other proportionally to the inverse square of their distance, the earth would be more flattened at the poles and surface gravity would decrease more strongly as the ship approaches the equator. In Newton's theory, the clock would require additional corrections of the pendulum length with latitude. Notably, Huygen's also gave an explanation for why previous measurements seemed to support the Newtonian prediction (fig. 3). During his experiments with constrained pendulums, he had realized that the bob only remains isochronous if its arc is kept sufficiently small. Huygens had advised the Alcmaer mariners to "make the pendulum move [...] roughly just 2 or 3 thumb-widths" (Huygens 1686). Huygens's not only provided new measurements but criticized previous discordant measurements (fig. 3) Hence, the in offered a causal explanation of the existing measurement discordance, predicated on his trust in his result and the assumption that surface gravity measurements could, in principle, lead to reliable determinations of the earth's figure.

WITH CORRECTIONS TO THE ALCMAER'S COURSE	DISCREPANCY IN LONGITUDE	DISCREPANCY IN KM
Based on rotation alone	0° 17′ E	19.0
Based on Varin's Δℓ in Goree	4° 55′ E	329.7
Based on Richer's Δℓ	1° 35′ E	106.2
Based on Newton's theory	0° 59′ E	65.9

Fig. 3: Disagreement between the longitudes determined for the Dutch island of Texel with (a) the help of a pendulum clock after a voyage from the Cape of Good Hope and (b) its astronomically determined longitude. The different rows reflect different possible corrections for the pendulum clock based on (i) Huygen's and (iv) Newton's predictions of surface gravity variations and generalisations of the variations measured by (ii) Varin and (iii) Richer. Reproduced with permission from Schliesser and Smith (2000).

2.3 The Cassinis

Both Huygens and Newton tried to substantiate their theoretical claims by appealing to pendulum measurements of surface gravity variations with latitude. The stipulated link between pendulum lengths and the earth's figure was based on abstract theories of gravitation. In light of their skepticism towards all such theories Giovanni Domenico Cassini, head of the Paris observatory, and his son Jacques carried out a much less theoretical measurement of the earth's figure from the 1690s onwards – explicitly addressing Huygens and Newton (Cassini 1720, 299). Rather than surface gravities, the Cassinis measured the latitudinal variation of the length of an equal arc of the meridian.

Their research represented the cutting edge of contemporary precision measurement as they employed calibrated rods as well as octant and sextant telescopes, which were prepared for both horizontal and vertical angular measurements (Cassini 1720, 51–61). They also geometrically corrected for potential errors introduced by altitude variations across the triangulation network by geometrically reducing all stations to sea level. While they measured the altitude of the stations optically, they controlled their results with subsequent barometer measurements (Cassini 1720, 135–55). The Cassinis found the meridian's northern section to be 97 toises shorter than the southern section, which the arcs measuring 57057 and 56960 toises respectively. Based on the Cassinis' data, both Huygens and Newton seemed to have been wrong: The earth was an oblong ellipsoid, and its equator was shorter than its polar axis. Generalizing this variation across all degrees of latitude implied a prolate ellipticity of 1/95 (or -95), a significantly stronger departure from sphericity than predicted by Newton and Huygens. In such a model, arc lengths increase as an elliptic function of latitude, with the highest increase per degree occurring just before 45°.

Jean-Jacques de Mairan, one of the foremost theoreticians in the *Académie*, also tried to reconcile the pendulum measurement with Cassini's results in 1720. His work did not evoke any previous theories about terrestrial gravity and did not characterize it as a force acting towards the earth's center. Rather he adopted a phenomenological outlook, trying to determine an empirical "law" of attraction that accounts best for the relation between surface gravity and latitude on Cassini's oblate spheroid model, where the surface gravity is indicated by the existing pendulum measurements. Marian then adopted the resulting best-fit variation as an empirical hypothesis and simply *defined* terrestrial attraction as a function of surface curvature, continuously increasing towards the earth's elongated poles. He argued that his adhoc characterization of gravity was the only account that was consistent with both arc and pendulum measurements (Mairan 1720, 252). Hence, Huygen's and Newton's measurement results were subject theoretical errors, introduced by relying on mistaken theories of planetary equilibrium figures that suggested an incorrect link between surface gravity and the earth's ellipticity.

2.4 The Newtonian response

In the second and third editions of the Principia (1713 & 1724), Newton explicitly responded to the alternative measurements of the earth's ellipticity. A striking and, so far, and unappreciated novelty in the revised propositions 19 and 20, is their explicit appeal to measurement error. Newton offered a reworked analysis of pendulum data, now including several new measurements by members of the Paris Académie. He dealt with the results by estimating their respective reliability and quantifying the impact of local sources of error on the length of an isochronous seconds-pendulum. He argued that all of the existing measurements the results Jean Richer were most trustworthy, appealing to the duration of the observation's series. Newton notes, moreover, that Richer's result fits exactly with Newton's prediction once it was corrected for thermal expansion.

Given that Richer also replicated his measurement multiple times and had used the same clock in Paris and Cayenne, Newton argued that the agreement with his theoretical prediction was sufficient to favor universal gravitation. During the consecutive revision for the third edition, Newton studied several new measurements by other French physicists which did not agree with Richer's initial result. He explained these deviations by postulating further errors in relative surface gravity measurements. In its final shape, the Principia refers to four different sources of measurement error to explain the divergence of other results from Richer's:

> "The discrepancy could have arisen partly from (i) [random] errors in observations, partly from (ii) the dissimilitude of the internal parts of the earth and (iii) from the height of mountains, and (iv) partly from the differences in heat [i.e., temperatures] of the air." (C&W, 477).

In his updated and extended analysis, Newton also responded to the Cassinis' measurement. As such, he offered precise predictions for the length of 1° meridian sections at different latitudes, which he now listed alongside his slightly adjusted predictions for pendulum lengths. These predictions correspond to latitudinal distances on the surface of an oblate ellipsoid with an ellipticity of 1/230 – i.e., Newton's original model for the earth's equilibrium figure. As such, they disagree starkly with the preliminary results that Jacques Cassini had presented at the Académie in the same year. Contrary to the Cassinis, however, Newton did not base these predictions on actual arc measurements but simply extrapolated from the gravimetric results.

Newton's protegee John Desagulier provided a more systematic criticism of the Cassinis' results in four papers that were successively published in the Transaction of the Royal Society throughout 1724. Contrary to Newton, he offered an extended quantitative error analysis. The power of Desagulier's criticism stems from two connected arguments. On a general level, Desagulier notes the methodological inferiority of comparing directly adjacent meridian sections. The less two arcs differ in latitude, the less they will differ in their length. In a more detailed discussion, he showed that, given their adjacent setup, Cassini's measurements were too sensitive to possible errors to support their conclusions. The upshot of Desagulier's empirical argument was that the geometric leveling was uncertain enough to introduce errors that were larger than the measured length difference between the two arcs (Desaguliers 1724).

3. Measurement without theoretical agreement: Towards a functionalist explanation

Between the 1680s and 1720s, the physical study of the earth's figure began to constitute a more or less cohesive problem, centered around the newly created quantity of planetary ellipticity and two different measurement indicators. Geodesists agreed on what we earlier referred to as the epistemic privilege of measurement: their mutual engagement and criticism was predicated on the belief that theoretically conceivable models also had to accord with the results of measurements. However, early geodesists did not agree on a shared theoretical framework to explain their choice of model or assess the relative merit of particular measurement outcomes. As we have seen, attitudes to competing gravitational theories of planetary equilibrium figures ranged from aversion (Huygens) and support (Newton, Desagulier) to qualified agnosticism (Cassini I & II, De Mairan). It is striking that early geodesy still experienced a somewhat cumulative and cohesive development, with scientists critically acknowledging each other's measurements and diagnosing potential errors in each other's results.

Linking these observations back to the structural explanation of measurement's epistemic privilege, we can immediately recognize that geodesists lacked what Mari et. al. call the "general model" of the target property or general theoretical laws from which such a model could be derived. The agreement was limited to the ellipsoid as a specific model of the earth, with (a) surface curvature and (b) gravitational acceleration defined as functions of its latitudinal coordinates. To carry out measurements of the model's ellipticity – geodesists' target quantity –, these two quantities (i) and (ii) were linked to two accessible quantitative indicators, namely the latitudinal variations in the of an isochronous length of seconds pendulums and meridional arcs. Since there was no agreement on a general background theory, the exact nature of the theoretical link between (I_1) and the earth's ellipticity was not generally agreed upon either. The postulated theoretical links from (i) and (ii) to pendulum and meridional arc lengths correspond to the basic constituents of what Mari et. al. call the model of the measurement process. Hence, early geodesy fail the structural criteria for measurement, at best qualifying as what Mari et. al. "candidate measure" (Mari et. 2017, 55).

	Description	**Illustration for Geodesy**
General Model	Quantitative theoretical description of **target property** in terms of **other quantities**, using **general laws**	**Polar or equatorial flattening** as described in theories of planetary equilibrium figures, in terms of a **general law of attraction** and the **centrifugal force, gravitational acceleration at the equator, and interior density distribution of a spheroid.**
Specific Model	Quantitative description of an **instantiation of that property** in a **specific object of interest**	Polar flattening as the **ellipticity of an ideal and homogenous ellipsoid representing the earth.**
Model of Measurement Process	Description of the interaction between the **specific model's parameters** and one or many **measurement instruments**, identifying and anticipating **possible sources of error** and (potentially) **quantifying uncertainty**	Link between **ellipticity** and the latitudinal variations in the lengths of **isochronous seconds-pendulums** and **meridional arcs**; distortions by **topographical irregularities**, **subterranean density distribution**, **expansion of instruments with temperature**; uncertainty due to **limited precision of telescopes, theodolites, and barometers** used in measurements and error corrections.

Fig. 4: Structural interpretation of measurement according to Mari et. al. 2017, applied to early geodetic measurement.

While geodesists did not agree on a general theory, they agreed on the ellipsoid as a stipulative model for characterizing their specific target quantity: the ellipticity of the earth. While Newton and Huygens had different physical arguments for the adequacy of that model, the Cassinis and de Mairan accepted it on purely pragmatic grounds – i.e., as an empirically useful characterization of the earth's shape. Nonetheless, geodesists agreed that they were engaging in a common measurement problem and that pendulum and arc measurements would be needed to provide evidence for the correctness of alternative background theories as well the magnitude of the model's ellipticity. Most importantly, they were having an intensive discussion about potential measurement sources of measurement *errors*.

Treating significant discrepancies in the inferences from directly accessible indicators to the relevant parameter of their quantity model as errors implies two epistemic commitments on the side of measurement agents. First, they have to be committed to the assumption that measurements of their target property should have the same outcome under the same conditions – a commitment that Hasok Chang dubs the "principle of single value" (Chang 2004). Since I agree with Chang's later assessments that the principle represents an assumption to which agents *commit* themselves by engaging in a certain practice, I will refer to it as *stability commitment*. Building on this basic commitment, measurement agents further need to believe that any variations between several outcomes measured under different conditions should either be (i) lawful, i.e., in accord with the modeled relation between indicators and target property or (ii) attributable to some external distortion. Call this the *nomicity commitment*. A simple and paradigmatic illustration of lawful variability is found in fulcrum balances, whose use in measuring relative weight commits agents to Archimedes's law of the lever. As the formal work by Patrick Suppes, Amon Tversky, David Krantz, and Duncan Luce has established, relying on quantity models with more detailed nomic structures increases the operational demands on the physical measurement system (Krantz et al. 1971).

Since measurement involves such distinct commitments from its participating agents, treating a system as measurable marks an active choice to participate in a distinctive kind of norm-governed research. In the initial stages of inquiry, choosing to pursue a specific measurement problem may not be backed up by a general theoretical model. Yet, it can still be justified in virtue of its *function* in enabling an inquiry with a particular epistemic structure, thereby establishing epistemic coordination between scientists. To understand what this epistemic coordination looks like, we have to look add the kinds of inference that are licensed by the stability and nomicity commitments. As we have seen, these two commitments allow agents to identify *errors* in numerical discordant measurements of the modeled property, which can then be traced back to an insufficient ability to (i) model the target system or (ii) detect and anticipate distorting influences. If a group of scientists engages in a measurement problem, they thus adopt a template for successively identifying discrepancies and anticipating their causes in theoretical mistakes or unaccounted distortions. Thus, after the first pendulum experiments and Newton's initial theoretical work in the Principia, we can observe an evolving and interactive commentary on measurement errors. In his reflection on the voyage experiment, Huygen's implied that earlier pendulum measurements were unreliable because the arc of the pendulum motion was not sufficiently constrained. Initially, Newton reacted to the extant pendulum data by correcting his model of the earth's internal density distribution, later by using experiments with thermal expansion to correct Richer's value. Cassini and de Mairan, in turn, accused Newton and Huygen's of introducing errors by relying on unconfirmed, alledgly mistaken theoretical assumptions. As Desagulier's work exemplifies, participants in a measurement problem can also opt for the inverse strategy and use theoretical knowledge about external distortions to call into question particular measurement outcomes. Thus, when Desagulier systematically developed Newton's criticism of Cassini's arc measurement, he estimated their sensitivity to known distortions (irregular altitude), undermining their inferential link to their model's ellipticity and, ipso facto, the physical earth's figure.

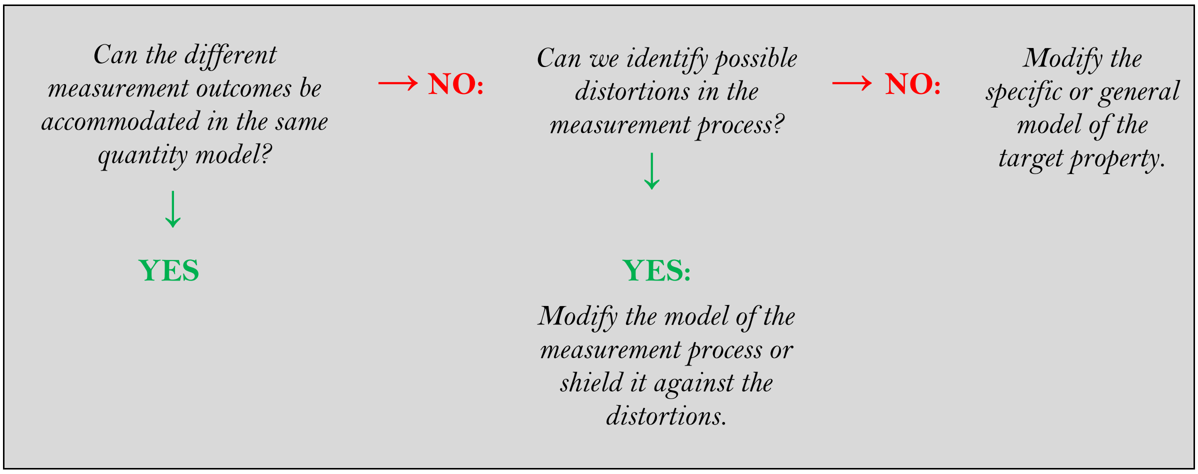

Fig. 6: Simple sketch of the epistemic structure of a measurement problem.

Taking stock, we can note that geodesists organized their collective inquiry around a measurement problem, implicitly subscribing to what I dubbed the epistemic privilege of measurement. Rather than embedding their measurements in a shared theoretical framework, they constrained their theorizing according to their ability to identify and explain measurement errors. In the absence of a shared background theory, I have traced back the ability to identify measurement discrepancies as errors to two implicit commitments to the stability and nomicity of measurements. While the structural interpretation and related epistemological views assume that the embedding of measurements in general theoretical frameworks explains its privileged epistemic function in science, my historical analysis suggests the inverse is true. The practice of measurement is rooted in the commitment of epistemic agents to stabilize (stability) and control (nomicity) the inferential relations between models and directly accessible indicators of a target system. These commitments have an autonomous *function* in rendering empirical discrepancies as measurement errors, permitting an inquiry into the external distortions and shortcomings of modeling assumptions. It has been widely noted that it is such interdependent and iterative revision of measures and models that can drive the *subsequent* development of general theoretical knowledge (Chang 2004; Smith 2014).

While my view breaks with the dominant explanation of measurement's epistemic privilege, it should be read as further specification, rather than a refutation of recent epistemological work on measurement. It is one of the key assumptions in recent studies that "measurement is a quasi-autonomous activity", deserving of an internal epistemology (Mitchell, Tal, and Chang 2017, 1) – an assumption very much at the heart of Mari. et. al's account of measurement's general inferential structure. Rather than rejecting this line of thought, I propose to further *extend* it to cases without secure theoretical foundations. Even quantity models without unequivocal theoretical support can facilitate the autonomous kind of inquiry we call measurement. Artificially restricting measurement to theoretically secure cases risks misunderstanding the basic position measurements occupies in the general architecture of scientific inference. Finally, we should note that my proposal implies no return to naïve, theory-neutral accounts of measurement. Pursuing the measurement problem often leads to the confirmation or articulation of impressive theoretical background theories (Newtonian gravitation being a case in point) and the iterative modification of initial measurement procedures (Mach 1896; Chang 2004). While measurement's epistemic privilege as a practice can precede general theories, its successful pursuit concerning particular attributes essentially involves theorizing.

Conclusion

Recent explanations of measurement epistemic privilege overestimate the importance of scientists' agreement on general theories for characterising target quantities. Using a case study from early physical geodesy, I have showed that measurement can occupy its central role in scientific inquiry even in the absence of agreement on such theories. Instead, measurements can be established based on stipulative and contextually specific quantity models and agents' commitment to the stability and nomicity of the inferential link between modelled quantities and their measurement indicators. Since these commitments license the identification of measurement errors in numerical discrepancies, the explanation of such errors allows scientists to subsequently articulate and test theories.

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