REALISM AND UNDERDETERMINATION
Some Clues From the Practices-Up

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SUMMARY: Recent attempts to turn Standard Quantum Theory (SQT) into a coherent representational system show considerable improvement over previous offerings, but such attempts still fail to settle important questions about the nature of material systems, as current theorizing about the latter effectively resolves into a multiplicity of incompatible statements about their nature, physical systems and their representation. Specifically, the most cogent proposals land in effective empirical underdetermination and mutual empirical equivalence, reviving old anti-realist fears about quantum physics. In this paper such fears are discussed and found unsound. It is argued that nothing of global skeptical or agnostic significance really follows from the kind of underdetermination presently encountered in fundamental quantum theory. The case is instructive, however, for what it shows about the characteristics and prospects of scientific realism as a perspective in contemporary philosophy of science.

To be a naturalist-realist about quantum theory requires one to have a properly physical interpretation of the quantum state, along with an explanatory account of quantum systems capable of accomplishing three tasks, at least: (a) answer the question about the theory's scope non-dogmatically, (b) account for state-reduction phenomena in physically respectable ways, and (c) account for the "classical" world of ordinary experience in appropriately scientific terms. Objectivist programs in foundational quantum physics have for some time been trying to achieve precisely this. Over the last decade, their efforts have matured into three particularly well-developed responses to the conceptual difficulties of the standard theory (SQT). These are: (1) Bohmian quantum mechanics (BQM) —an offspring of a seminal proposal of the nonlocal hidden variables theory introduced by Bohm in the early 1950s[1]; (2) the "Many Decohering Worlds" approach (MDW) —an offspring of the "Many Worlds" interpretation of QT_0, introduced by Everett later in the same decade[2]; and (3) the Spontaneous Collapse Approach (SCA) —the closest there is to a direct descendent of SQT[3]. BQM radically challenges the projection postulate and the completeness of SQT as a theory of material systems, and critically reinterprets the latter's probabilistic algorithm. MDW radically challenges the projection postulate while critically reinterpreting the probabilistic

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[1] . Bohm (1952/1983).
[2] . Everett (1957).
[3] . Advanced most influentially in Ghirardi, Rimini & Weber (1986).

algorithm and revising the completeness assumption. Finally, SCA critically revises the projection postulate (which it does not eliminate), the standard probabilistic algorithm, and the completeness assumption. There are, thus, at least three competing approaches for the deep representation of the material world[4]. Each yields a prospectively fruitful explanation of the domain covered by SQT, none is without some explicit fertility: BQM encourages work of cosmological interest on superluminal signalling prior to the establishment of quantum equilibrium[5]; MDW is renown for its cosmological openings[6]; SCA promotes new ways of looking at thermodynamics[7].

How do these approaches fare in terms of internal consistency, however? All the early formulations were abundantly *ad hoc,* opaque, and vague, but the descendant theories advanced in recent years show marked improvements in this regard. Thus, although initial versions of BQM were reproachable for their artificiality, subsequent work has managed to provide some physical motivation for most of the Bohmian rules. Much of what started as a patchwork of assumptions lacking internal coherence drops out nicely from theory in recent versions of the Bohmian approach. Work by Valentini[8], for example, offers plausibility arguments in which random subquantum interactions drive systems to conditions of equilibrium, in which the probabilistic distributions spontaneously correspond to those given by the standard rule. Valentini further establishes that, once the universal state satisfies the condition of quantum equilibrium, the wave function for any individual subsystem also satisfies this equilibrium condition *for measured values*. In his particular version of the Bohmian approach, the world possesses signal locality only in a contingent historical way, and then only after equilibrium is reached, being fundamentally nonlocal in its structure outside that regime.

As for MDW, the best versions no longer assume classical features from the top-down on arbitrarily chosen relative branches of the total state, but let them emerge naturally under special conditions. Central to this move is MDW’s literal reading of Schroedinger-cat situations, specifically the idea that our experience as *observers* does not correspond directly to the universal wave function. From this perspective, it is the various post-measurement branches of the wave function, not the total state, that correspond to the distinct results that are observed in practice —what we perceive as an "instantaneous collapse" of the wave function being understood as part of the branch-rooted, branch-relative reality of the phenomenon we call "awareness"[9]. Nevertheless, some critics remain particularly unhappy with the MDW approach, charging that it lacks sufficient internal conceptual integrity[10]. Though these are unfinished debates,

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[4] . The specific versions of these theories considered in this paper have been selected with internal consistency as guiding criterion.

[5] . Valentini (1991).

[6] . See, for example, Gell-Mann & Hartle (1993).

[7] . Cordero (1995).

[8] . Valentini (1991).

[9] . For advances in this direction, see Saunders (1993), Donald (1995), and Lockwood (1996).

[10] . Lockwood (1996) contains good summaries of the relevant debates. For an

engaging responses on behalf of MDW are available[11]. It would seem inappropriate, therefore, to summarily reject MDW (or any of the other reviewed approaches) on charges of serious internal inconsistency.

Finally, regarding the SCA approach, its most influential rendition to date springs from a proposal originally introduced by G.C. Ghirardi, A. Rimini, and T. Weber (GRW)[12], which has been transformed over the last decade by Ghirardi and a team of collaborators into a detailed theory with advances toward both a proper relativistic version and a mass-density field formulation[13]. The specific models advanced by the Ghirardi team faces some as yet unresolved difficulties, but these do not seem to compromise their larger project[14]. Numerous facts from the laboratory require that collapses processes flow superluminally, however, and this creates a difficulty with regard to high-energy generalizations of SCA. Their time ordering can be thus strongly frame-dependent. Wave function collapses respect Lorentz invariance at the stochastic level, but individual processes are a different matter. A "compromise solution", well received in the SCA camp, is to link collapse processes to the frame-dependent simultaneity relation and relativize them to flat space-like hyperplanes[15].

PROSPECTS OF EXPERIMENTAL RESOLUTION

BQM, MDW and SCA do not just yield different pictures of physical reality; they also make different predictions about it. This comes out as differential forecasts for the values of certain quantities. For example, SCA and MDW (QT_0) predict disparate values for $(\Delta p)^2$ and $(\Delta X)^2$; also, as explained before, Bohmian assignments of probabilities are not always exactly those of MDW or SCA[16]. Hopes of experimentally finding out which (if any) of these approaches provides the most credible unveiling of the *nature of material systems* reached a peak in the early 1990s. One promising arena seemed to be provided by quantum optical phenomena, especially in the context of studies of the intermittency of resonance fluorescence in three-level atoms[17]. A prospective experimental resolution of many major foundational questions about the nature of material systems seemed finally at hand –such questions as whether superpositions of the "Schroedinger’s cat" variety actually come to an end, whether the world develops in a deterministic or stochastic way, and whether physical objects develop determinate trajectories in space-time.

FRUSTRATED HOPES

It soon became clear, however, that actual workings in the world

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analysis of the relevant charges see Papineau (1995).

[11] The first issue of Volume 47 (1996) of the British Journal for the Philosophy of Science contains an excellent survey of the main positions.

[12] Ghirardi, Rimini & Weber (1986).

[13] See, in particular, Ghirardi, Grassi & Benatti (1995), and references therein.

[14] Cordero (1999).

[15] Fleming (1989).

[16] Ghirardi, Rimini & Weber (1986), Valentini (1991).

[17] See, for example, Cook (1990).

seriously spoil the prospects of the mentioned theories' predicting different *observable* phenomena. In particular, the universality of the decoherence effect and its impact on the predictive power of proposals like SCA and MDW has been the subject of detailed theoretical analyses, especially through studies of the scattering of an incoming object by macro-objects (ranging from specks of dust to bowling balls). Scattering dampens interference terms in the position representation of the density matrix associated with the scattering center (with $|x>$ representing the position eigenstates of the macro-object)[18]:

$$\rho(x,x',t) = \rho(x,x',0)\ \exp[-\Lambda t(x-x')^2. \quad (1)$$

The important finding is that, when ordinary macro-objects are involved, the above dampening effect becomes dramatically fast-paced. Even in the kind of vacuum environment available in any imaginable laboratory, the number of scattering process contributing to the destruction of interference turns out to be enormous. Values obtained for relevant milieus show the extent to which molecules are the dominant decoherence agent in our part of the universe[19]. Collapse phenomena (measured by the GRW effect) end up knocked out of sight by the weight of ubiquitous environmental factors —vacuum levels in outer space turn out to be damaging enough as well. Attempts to trace the effects of Bohmian non-equilibrium around fluctuations away from equilibrium would seem doomed to fare no better. So, decoherence phenomena spoil the envisaged prospects of being able to experimentally choose between the reviewed total theories. Such phenomena burden experimental access to the world with a kind of irreducible "experimental astigmatism" which, if the figures obtained so far are representative, has the effect of averaging out the distinctive ontological features of such proposals as BQM, MDW and SCA.

Perhaps, then, there is effectively no observational way to tell about the physical underpinnings of SQT. If this fear is correct (and it is not completely clear that it is), what if any would be the epistemological message here? Even if it were accepted that BQM, MDW and SCA are observationally equivalent proposals, one of them might still be clearly preferable to the rest on other grounds, rational theory choice having more resources than just predictive power. In this regard, one major strategy consists in checking observationally equivalent candidates against well-established prior information about relevant domains. This is particularly effective when sufficiently general and uncontroversial principles are available which can help one choose among observationally equivalent contenders[20]. In the case at hand, an obviously relevant

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[18] . The quantity Λ above is proportional to the square of the wave number, the incoming flux and the effective cross section. It measures how fast interference between terms for different positions disappears as a function of distance in the course of time, thus functioning as a "localization rate".

[19] . See, for example, Tegmark (1993).

[20] . Compelling cases are discussed in Norton (1994).

consideration is generalizability to a relativistic version, as Lorentz invariance is generally agreed to hold in a fundamental way in nature.

BQM and SCA clearly involve processes that violate the strict traditional principle of locality. Though for different reasons, in BQM and in SCA the behavior of some separated systems cannot be explained by any local theory. Bohmian systems that have interacted in the past can interact superluminally through the connection provided by the guidance condition, a mode of connectivity between spatially separate systems that clashes with strict Lorentz invariance. In SCA, the clash with invariance comes from the fact that state reduction is generally a superluminal process that influences the structure of the wave function over the entire prior support of the state. While the quantum stochasticity involved in this mode of evolution makes it impossible to use it for signalling, from this perspective something physical (projection of the wave function in ordinary space) changes over distance essentially in no time. Much better off in terms of Lorentz invariance seems MDW. In an experiment of the Einstein-Podolski-Rosen type involving a pair (α,β) of particles, for example, the total MDW quantum state is not affected either stochastically or nonlinearly by the measurement process. Nor are any of the relevant local states affected superluminally. From the density operator ρ representing the total system, local density states for the components α and β can be uniquely specified, and it is easy to show that a measurement on component α does not change the local reduced state of the world around β.

It is not clear, however, how big a victory this is for MDW, as the final verdict hinges upon *how credible strict Lorentz invariance is as a constraint on physical theories*. Two relevant issues in this regard are (i) the relationship that relativistic and quantum physics actually maintain; and (ii) the relationship that, in light of present knowledge, it is legitimate to expect between a satisfactory theory of matter and Lorentz invariance. Quantum theory and relativity theory are conceptually very different[21]. First, contrary to what elementary pictorial representations suggest, the wave function does not primarily live in ordinary geometrical space but in *configuration space*. Secondly, successful relativistic generalizations of ordinary SQT (quantum field theories) do exist, but it is significant that all these really presuppose is stochastic rather than strict Lorentz invariance. To complicate matters further, the relation of the "best" theory of spacetime available (General Relativity) with quantum physics is far from clear. The circumstance that Schroedinger-cat situations involve superpositions of spacetime manifolds hints to a deeper role for configuration space in physics. What a better theory than general relativity and SQT might claim about all of this remains, for now, in the realm of speculation.

Meanwhile, the reasons for imposing strict Lorentz invariance as a criterion for theory selection seem to be less

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[21] See, in particular, Maudlin (1994).

than fully convincing. This connects with the second suggested concern: To what extent is Lorentz invariance part of the conceptual background to physical theorizing? If tension with strict Lorentz invariance is not deemed fatal, then neither BQM nor SCA can be disallowed on grounds of their violations in this regard. One might simply accept that a preferred family of hyperplanes is part of the intrinsic structure of spacetime. Alternatively, one might bite the bullet and relativize wave function collapse to light-like hyperplanes[22]. One way or the other, it seems that one cannot rule out views that limit spacetime physics to a theory of stochastic symmetries on the basis of *current background knowledge*. Still, even if one agreed that the BQM, MDW and SCA are comparable in such respects as fruitfulness, predictive power, internal and external consistency other learned criteria of theory choice might still tip the balance in clear favor of one of them. That, however, appears doubtful in the present case. Simply put, the reviewed theories seem to land us in a case of underdetermination –theorizing about the nature of material systems effectively resolves into a multiplicity of absolutely incompatible statements about physical reality.

Now, wasn’t this the kind of result skeptical and agnostic readers of science had led us to expect all along? Should it not have been clear enough that "deep" explanatory theories are bound to prove either false or empirically underdetermined? I suggest that the answer to these questions is "No". Nothing of global skeptical significance appears to really follow from case considered in this paper. Nevertheless, the case is instructive for what it shows about the characteristics and prospects of the scientific realist perspective in general, and its viability and vibrancy in contemporary philosophy of science. [I take scientific realism as the naturalist view according to which (a) we can decide whether theories are approximately true of reality, the nature of which does not depend on our concepts and representations, and (b) the way of knowing involved in reaching such a decision is the scientific way of knowing].

SUSPENDING BELIEF

Three points about the encountered underdetermination need to be noted at this stage: (1) its seemingly limited scope within the total theoretical structure; (2) its manifest contingency upon certain facts regarding the present state of our part of the universe; and (3) its tension with abstract philosophical attempts to differentiate belief in terms of distinctions of the theory/observation variety.

(1) Scope. Clearly the underdetermination at hand is of *limited scope*. The robust commonalities between the competing theories are legion: all associate the quantum state with a peculiar physical field, all include the Schroedinger equation in the dynamics, all endorse a strong form of ontic-structural nonseparability, all agree on geometrical relations between sub-systems (internal molecular shapes, atomic and quark structure, etc.). Divergence is confined to certain specific respects and

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[22] . Fleming (1989).

degrees of precision in the modelling, with clear impact only on answers to such questions as whether dynamical properties are absolute or relative-state, whether the world proceeds deterministically or indeterministically, whether the world ontology is dual (particle+field) or single (just the quantum field). So, although the case makes for an intense ontological debate, its corrosive power on belief seems confined to just some regions of the full models advanced. The encountered underdetermination strikes realist theorizing only from a certain level of descriptive depth down, and then along some structural lines (aspects as profound as the group-theoretic symmetries are untouched by the debate, at least in stochastic terms). Above that level the models yielded by the three reviewed theories converge splendidly through effective partial isomorphisms that reach well into their respective theoretical fabrics to a very high degree of approximation.

What do these observations amount to in concrete terms? Suppose that someone wants to understand a certain measurement device, say, a detector of charged nuclear particles. Then a hierarchy of models is available to him, ranging from ones that are equally acceptable to defenders of SQT, BQM, MDW and SCA, to ones which are partial to only one of the points of view at the most. At the shallowest hierarchical level the four approaches share a thick body of modelling and relevant prior knowledge. For example, all agree that when an incoming charged particle interacts with the electrons in atoms along its way, that the ensuing energy exchange causes many electrons to leave their atoms and the incoming particle to slow down —a process that, for incoming particles with energies in the Mev range, easily leads to the generation of thousands of electron-ion systems in a medium. The agreement compounds. There is little disagreement among the various partisan groups about the constitution of, say, a scintillation detector for energetic charged particles: all agree that the device design exploits the light yielded in a crystal when electrons removed from their locations by an incoming energetic charged particle recombine (scintillation); that the light so produced is made available on a surface with a large cross section for a photoelectric effect; that the electrons thus freed are then accelerated by an electric field toward a plate made of material whose surface electrons are easily released by collision with the incoming electrons, typically at the rate of four per collision; that the resulting electronic population is then accelerated toward a second plate of the same kind, and then to a third, and so on until "enough" charge is available for collection by a capacitor producing a voltage proportional to the charge received, this charge flowing off through a resistor in parallel with the capacitor; that magnitude of the output pulse is proportional to the total number of electrons emitted in the photoelectric stage, and so also proportional to the scintillation photons generated in the first stage of the measurement process; that, if the object particle is stopped in the crystal, the final electric pulse is proportional to its initial energy, which can thus be measured. All this agreement, in spite of the fact that most of the terms just used have different "meanings" in the four highlighted theories.

Again, theoretical models of this kind of apparatus are available in the standard physicist's bag —indeed a hierarchy of them in terms of accurate representation of the detector, regarded as a structure of possibilities. At the simplest level, there is a semi-classical model, much along the lines of Bohr's early theory, in which electrons have well-defined atomic orbits, and forces follow the classical laws. Here, the triggering incident is portrayed as an incoming charged particle of velocity v_p in, say, the x direction that enters the apparatus and progresses through a medium populated by N_1 atoms of atomic number Z per unit of volume. When this incoming particle passes a given atomic electron with closest distance l, the net impulse p_e transferred to the electron in a direction perpendicular to the incoming particle's trajectory is given by the following integral:

$$p_e = \int_{-\infty}^{\infty} (e^2/4\pi\varepsilon_0) \sin\theta \, d\theta. \qquad (2)$$

This yields a kinetic energy transfer to the electron given by:

$$K_e = e^4/(8\pi^2\varepsilon_0{}^2 l^2 m_e v_p{}^2) \qquad (3)$$

A straightforward calculation of the energy loss for the incoming particle over a path of length dx yields

$$dE = -e^4 N_1 Z/(8\pi^2\varepsilon_0{}^2 m_e v_p{}^2)\ (2\pi l\ dl/l^2)dx \qquad (4)$$

Defining I_{Av} as the average ionization potential for the atomic electrons in the chosen medium, integration over l, yields, using a semi-classical determination of the spatial range of significant interaction[23], using the symbol "ε" to represent the margin of error imposed by internal simplifications and idealizations incurred at the level of auxiliary assumptions and models:

$$dE/dx = -e^4 N_1 Z/(4\pi^2\varepsilon_0{}^2 m_e v_p{}^2)\ m_e v^2/I_{Av} \pm \varepsilon_{E'}{}^{(I)}. \qquad (5)$$

A second, certifiably more accurate model of the same relevant domain, is provided by SQT. It yields:

$$dE/dx = -e^4 N_1 Z/(4\pi^2\varepsilon_0{}^2 m_e v_p{}^2)\ \ln(2m_e v^2/I_{Av}) \pm \varepsilon_{dE'}{}^{(II)}. \qquad (6)$$

A third, yet deeper level of modelling comes from the standard relativistic theory. It yields:

$$dE/dx = -e^4 N_1 Z/(4\pi^2\varepsilon_0{}^2 m_e v_p{}^2)\ \{\ln(2m_e v^2/I_{Av}) - \ln(1 - v^2/c^2) - v^2/c^2\} \pm \varepsilon_{E'}{}^{(III)}. \qquad (7)$$

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[23] . See Cohen (1971); for complete calculations see Evans (1955).

Better models are obtainable, but the point of bringing the above expressions to the fore is just to highlight the availability of a descriptive hierarchy in ordinary science. Scientific description proceeds through a kind of modelling that is both guided by relevance consideration and centered on specific respects and degrees of precision. In the specific case just considered, the descriptive hierarchy is clearly progressive, as the theories underpinning each of the modelling stages form a clear progression in terms of testable representational accuracy. This is possible largely because the available experimental discrimination for the relevant quantities is sharper than the calculated theoretical differences. Situations focused on the "deeper" models provided by BQM, MDW and SCA for the device are different in that, in their case, *current experimental discrimination is coarser than the differentials yielded by the competing theories* —hence underdetermination becomes an issue at this level. The resulting modelling reaches deeper into the nature of material systems —but not credibly.

(2) Contingency upon details regarding the way the world and us are actually constituted. For example, the potential empirical differentiations mentioned earlier in connection with work by Ghirardi et al. and by Valentini show that the underdetermination encountered is defeasible, at least in principle. As for the way in which decoherence spoils differential predictive power for the competing approaches, the encountered difficulty is manifestly contingent upon some "unfortunate" facts about the world. Whether physicists ever manage to articulate experiments capable of discriminating between the deep theories on the table remains an open matter. No grand form of underdetermination thus seems to be served by the case.

(3) Further, no philosophical theory/observation distinction seems to be served by the encountered underdetermination. For one thing, the credible part of the discussed theories includes plenty about "unobservable" entities and processes which are nonetheless distinctly quantum mechanical. Take, for example, basic quantum mechanical model of the water molecule, with its atom of oxygen bonded to two atoms of hydrogen, the latter making an angle of about 103^o in "normal" thermodynamical conditions. Stuff like this is contained in approximate partial models shared by all the reviewed theories. Furthermore, this portion of the theoretical narrative is as trustworthy as the most trustworthy ordinary talk about, say, cats and their configuration. In particular, it seems impossible to challenge certain levels of discourse about quantum mechanical unobservables —regarding, say, the existence and geometric structure of water molecules or the quark configuration of protons, the microscopic lattice of graphite, the angular wave functions linked to atomic d−states, energy nuclear levels, fundamental symmetries, and much more— without compromising talk about ordinary observables as well, unless epistemic standards are arbitrarily raised against theories. So, even though objectivist quantum theory leaves us in the dark regarding many ontological aspects, it does manage to tell us a great deal about what actually exists and what it is like. The point is this: despite the ontological

underdetermination displayed by current objective QT, up to a certain significant level of descriptive depth, *the credible narrative made available by QT is as credible as the best common claims about ordinary objects.*

To suggest otherwise would seem to assume that a scientific model cannot be trusted at any level unless everything it says about the central entities it postulates is credible. But, what grounds are there for that? If history shows anything, it is that we can scientifically study and discover facts about a domain in a piece-meal fashion, without being committed to any physical quantity as constituting it. From a certain descriptive level down, real systems could be BQM systems, MDW systems, or SCA, or indeed any physical quantity compatible with the uncontroversial parts of the standard theory. Current criteria fail to discriminate between the noted options. We are left with a plurality of underdetermined pictures, and with many corresponding "whys": Do superpositions of the "Schroedinger's cat" variety actually come to an end? Are the basic laws of nature deterministic or stochastic? Do physical objects develop determinate trajectories in space-time? Are empirically accessible quantum state structures relative or absolute? Thanks to theories like BQM, MDW and SCA, however, we now know that comprehensive answers to these deep questions can at least be envisaged. This dissolves at least one objection against quantum mechanical realism: we end up with not just one but three seemingly "properly physical", realistically interpretable theories of the quantum state.

THE CLUES ELABORATED

More than a possibility proof for quantum realism seems to be advanced by the reviewed case, however. The previous considerations connect rather well with ongoing efforts to articulate a properly *naturalized realism* –one in which the emphasis is on prevailing scientific criteria for the acceptance and rejection of theoretical proposals rather than on notoriously dubious considerations about language and reference. From such a perspective, the realist's primary interest focuses on theories and models which, like the most credible models about the ordinary world, are both "successful and beyond reasonable doubt" by current scientific lights.

Spelling out what success and freedom from specific doubts amount to here is of course a delicate matter, but surely predictive power deserves center stage in any first approximation to the matter. Apart from consistency with established knowledge, prediction is manifestly the tool of choice for advancing credibility –not a foolproof tool, nor the only one, just the favorite tool. Accordingly, a theory or model M is prima facie credible if: (a) it leads to predictions about data obtained by scientific observation involving real-world objects from the domain of study; (b) these predictions have been confirmed; and (c) relative to knowledge available prior to M, the predictions in question should have seemed most unlikely to obtain unless M fitted the intended domain to a demanding degree of approximation[24].

The rise of scientific doubts (as opposed to merely "global" or "metaphysical" ones)[25] against a particular theory or model is equally delicate. Here, again, unfulfilled prediction remains the simplest triggered in standard scientific practice. When a prediction fails the refutational arrow moves rarely in a straightforward way. It needs to be observed, however, that the more precise areas of scientific modelling have a compelling story to tell about how they manage to avoid holistic paralysis. One type of common situation, carefully analyzed by Balashov[26], focuses on cases in which the study of multiple pieces of recalcitrant data against an otherwise well-established theory or model results in the identification of an specific intersection of conjunctions of auxiliary models and assumptions, such that saving this element is consistently accompanied by degeneration of the whole system, as measured by suitable empirical criteria.

Much more can be said about current scientific methodology, of course, but the jest of the above considerations is, I hope, clear enough. The deep explanatory quantum theories reviewed in this paper land in empirical underdetermination and equivalence because their distinctive cores turn out to be effectively screened by nature from gaining differential attributions of either success or failure. Conjoined with credible models of situations and conditions currently available to experimenters, the cores in question result in differential predictions that are too tiny relative to the level of blurring introduced in the laboratory by ordinary decoherence —a process which, apart from being constitutive of experimental error, is incorporated into all the approaches in question.

Nonetheless, if the previous considerations are approximately correct, *the scope and variety of quantum mechanical modelling about which one ought to be no less of a realist than one is about the ordinary world remains overwhelming large*. And this in spite of the authentic scientific underdetermination presently encountered at some deep levels of scientific theorizing.

NOTES

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[24] Giere (1988), especially Chapter 7.
[25] Shapere (1984), especially Chapter 19.
[26] Balashov (1994).

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