

Is Logic Empirical? Logical ‘Conventionalism’ from an Empirical Standpoint

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Abstract

The laws of classical logic are taken to be logical truths, and logical truths are taken to objectively hold. However, we might question our faith in these truths: why are they true? One often avoided approach is logical conventionalism, because it makes the logical truths dependent on somewhat intersubjective linguistic conventions. Another approach, proposed by Putnam (1975) and more recently Dickson (2001) or Maddy (2007), is to adopt empiricism about logic. On this view, logical truths are true because they are true of the world alone – this gives logical truths an air of objectivity unlike logical conventionalism. Putnam and Dickson both take logical truths to be true in virtue of the world’s structure, and the structure of the world is to be understood to be given by our best empirical theory, quantum mechanics. As it turns out, the structure of quantum mechanics apparently makes true the laws of quantum logic, and falsifies (one half of) the distributive law, something which was taken to be a logical truth under classical logic. Empiricists take this to indicate that the distributive law was not a logical truth to begin with. However, this argument assumes that there is a single determinate structure of the world prescribed by quantum mechanics. In this essay, I argue that this assumption is false, and that the structure of the world is underdetermined in quantum mechanics. Likewise, the choice of ‘true’ logic, as given by the world’s structure, is also underdetermined. This leads to what I call empirical conventionalism: the world alone fails to determine our logical truths. We need something broadly intersubjective, and thus less than objective, to fix our choice of logic even under empiricism. An attempt to avoid one form of conventionalism has thus led us back to another.

1 Introduction

Consider the *distributive law over conjunctions* for all sentences p , q , and r :

$$(\text{CON}): p \text{ and } (q \text{ or } r) \leftrightarrow (p \text{ and } q) \text{ or } (p \text{ and } r)$$

Alongside other ‘laws’ of classical logic, CON is usually taken as a logical truth – meaning that regardless of the contents of p , q or r , CON objectively holds.

We might ask: why are logical truths true? One approach takes logical truths to follow from meanings of subsentential operators. This seems to lead to logical conventionalism, (roughly) the thesis that logical truths, e.g. CON, are true ‘in virtue of meaning’ or ‘true by convention’ (Warren, 2016, 2). However, logical conventionalism is intuitively

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unsatisfactory for explaining CON's objective truth since it makes CON's truth dependent on (at best) intersubjective conventions.²

One attractive alternative is empiricism, which claims that the facts determining choice of logic are not conventional because they are given by the world alone, independent of human conventions. Empiricism, taken as the thesis that the world alone determines our logic, *prima facie* avoids the problem of intersubjectivity: a logic is objectively true because it is validated solely by a mind-independent world. Logical truths hold independent of us because there are empirical facts of the matter deciding the 'true' logic.

How is a logic validated by the world? Maddy (2007, 226) proposes that 'logic is true of the world because of its *underlying structural features*'. For example, I might say that CON is validated by the world's CON-structure: whenever I have a red ball *and* either a blue *or* green ball, I have *either* a red *and* blue ball, *or* a red *and* green ball. Conversely, to say that CON is *not* validated is to say that the world does not have a CON-structure.

The difficulty, then, is determining the world's structure: the empiricist strategy is to 'read off' logic from *our best (most empirically successful) sciences* (Putnam, 1975, 179), which I take to be quantum mechanics (QM).³ Putnam thinks this approach is superior to logical conventionalism:

Anyone who really regards the choice of a logic as a 'matter of convention', will have to say that whether 'hidden variables exist', or whether, perhaps, a mysterious' disturbance by the measurement exists', [...] is likewise a matter of convention.

(Putnam, 1975, 191-192)

If relevant empirical facts about QM determining the 'true' logic appear determinate and objective, empiricism has an edge over logical conventionalism in explaining CON's objective truth. However, CON appears false in the logic of quantum mechanics, quantum logic (QL). Empiricists like Putnam (1975) and Dickson (2001) interpret this to mean that CON *is* false, and QL is instead the 'true' logic (Dickson, 2001, 2). The objectivity of empiricism thus comes at a cost: CON is, after all, a *law* of logic, which we had hoped to establish as objectively true. The empiricist might bite the bullet here and find forsaking CON a worthwhile price for reclaiming objectivity for logic.

Here, I re-examine this strategy, specifically its presupposition of a determinate world-structure prescribed by QM. In this essay, I show that the choice of world-structure in QM is *empirically conventional*: nothing within QM's formalism, from which all empirical results are derived, can determine the choice of world-structure, or 'true' logic. The world alone fails to decide our logic. Putnam's challenge to the conventionalist thus fails: those relevant empirical facts which determine the 'true' logic *are* still conventional, leaving us with yet another form of conventionalism.

In §2, I introduce basic QM formalism – the backbone of QM's empirical success. In §3 I define QL on QM's structure, and show why CON *prima facie* fails in QL. In §4 I present

² Quine (1936) remains the starting point against explicit conventionalism. However, see Warren (2016) who argues for implicit conventionalism.

³ I employ non-relativistic QM here, and assume that the conceptual problems afflicting various interpretations presented here in relativistic QM are resolvable – if so, the issues discussed later remain.

two well-known interpretations of QM, each with a different interpretation of QM formalism and thereby different conclusions about QL's status and CON. In §5, I argue that the empirical results of quantum mechanics *underdetermines* interpretation, and leads to empirical conventionalism about QM's interpretation. A fortiori, the 'true' logic is underdetermined. This leads to a conventionalism about logic, from within empiricism.

2 Basic Quantum Mechanical Formalism

Before I describe QL, I first present QM's formalism underpinning it: "a set of equations and [...] calculational rules for making predictions that can be compared with experiment" (Cushing, 1993, 265). The formalism alone is enough to explain all empirical results, and its empirical success is undisputed. As Cushing notes, most physicists, in experimental contexts, focus *exclusively* on the formalism and 'getting the numbers right' (ibid, 265).

Systems: a quantum system (the quantum analogue of classical physical systems) is represented by some *Hilbert space* \mathfrak{K} (i.e. a complex complete inner-product vector space).

Observables: each observable (measurable property of the system), e.g. spin or momentum, is represented by a Hermitian operator⁴ with an associated family of projection operators, each projecting onto (normalized) mutually orthogonal one-dimensional subspaces of some \mathfrak{K} . The set of these subspaces form an *orthonormal basis* of some \mathfrak{K} (i.e. they generate the span⁵ of that \mathfrak{K}).

States: Every one-dimensional subspace of an orthonormal basis is an *eigenstate* of the observable, and represents a possible *state* of the system (e.g. spin-up, spin-down). However, since \mathfrak{K} is constructed from the span of such subspaces, all of their linear combinations are also inside \mathfrak{K} , and likewise possible states of the system: if ψ and ϕ are distinct eigenstates of a system, then the *superposition* of the two eigenstates, a vector $a\psi + b\phi$, where a and b are complex numbers such that $|a|^2 + |b|^2 = 1$, is *itself* a possible state of the system.

Dynamics: A wave equation (e.g. *Schrödinger's equation*) governs the dynamics of states in \mathfrak{K} over time. A solution to this equation is a wave-function Ψ describing how a system deterministically evolves over time.

Composite Systems: the tensor product \otimes of multiple systems describes these systems. Given two systems 1 and 2 with the bases:

$$\{|+\frac{1}{x}\rangle, |-\frac{1}{x}\rangle\} \text{ and } \{|+\frac{2}{x}\rangle, |-\frac{2}{x}\rangle\}$$

A new basis for the composite system, \mathfrak{K}_c , is constructed with the following possible states:

$$\{|+\frac{1}{x}\rangle \otimes |+\frac{2}{x}\rangle, |+\frac{1}{x}\rangle \otimes |-\frac{2}{x}\rangle, |-\frac{1}{x}\rangle \otimes |+\frac{2}{x}\rangle, |-\frac{1}{x}\rangle \otimes |-\frac{2}{x}\rangle\}$$

⁴ An operator A on \mathfrak{K} is *Hermitian* if, for all vectors u and v , $\langle u|Av\rangle = \langle Au|v\rangle$. For more details, see Hughes (1993).

⁵ The *span of vectors* is the set of all their possible linear combinations.

Notably, these states are irreducibly composite: For example, $|-\frac{1}{\sqrt{2}}\rangle \otimes |+\frac{2}{\sqrt{2}}\rangle$ cannot be broken down into independent sub-states $|-\frac{1}{\sqrt{2}}\rangle$ or $|+\frac{2}{\sqrt{2}}\rangle$; these states are *entangled* and must be described together. This is the source of Einstein-Podolsky-Rosen correlations⁶ and quantum non-locality.

Measurements: Lastly, given a measurement on a system in state ψ , the projection postulate states that:

$$\psi = \sum_k a_k \psi_k \rightarrow \psi_j$$

Upon measurement, ψ is ‘collapsed’ onto some one-dimensional subspace representing an eigenstate. If ψ is some superposed state $\psi = a\psi_1 + b\psi_2$, the postulate states that ψ ‘collapses’ into one of two eigenstates ψ_1 or ψ_2 , with the *Born rule* prescribing probabilities for the states occurring as $|a^2|$ and $|b^2|$ respectively. Thus, in considering whether a system is in state ψ_1 or ψ_2 , we must calculate it via calculating the probabilities of $|a^2|$ and $|b^2|$ from $a\psi_1 + b\psi_2$.

3 Basic Quantum Logic

3.1 \mathfrak{K} ’s structure, and QL

The set of all possible subspaces of \mathfrak{K} , $S(\mathfrak{K})$. $S(\mathfrak{K})$ has a structure: it is a *partially ordered lattice* $L(\mathfrak{K})$, with $P \leq Q$ defined as P being a subspace of Q in \mathfrak{K} . For any two subspaces in $L(\mathfrak{K})$, there is a greatest subspace common to both (the *infimum*), and a smallest subspace containing them both (the *supremum*). Following Hughes⁷, I define meet (\wedge) and join (\vee) on subspaces in $L(\mathfrak{K})$:

$$\text{(Meet)} P \wedge Q = P \cap Q$$

$$\text{(Join)} P \vee Q = \bigcap \{N : N \in S(\mathfrak{K}) \text{ and } P \leq N, Q \leq N\}$$

While the meet/infimum of two subspaces is equivalent to their intersection, the join/supremum of two subspaces is *not* their union in the classical sense. Rather, it is their span, viz. the plane containing the two subspaces and all their possible linear combinations. Indeed, a union of two subspaces is in general *not* a subspace in \mathfrak{K} .⁸ This reflects QM’s principle that, if any two states are possible states of a system, then, at the same time, so too is their linear combination.

In $L(\mathfrak{K})$ every subspace is a subspace of \mathfrak{K} , and the subspace of every member of $L(\mathfrak{K})$ is the origin vector 0. Hence, \mathfrak{K} is the *maximum element*, and 0 the *minimum element*, of $L(\mathfrak{K})$.

⁶ See Fine (2014) for an excellent historical summary on Einstein-Podolsky-Rosen correlations.

⁷ See Hughes (1994) for a full formal account of **QL**

⁸ Specifically, $P \cup Q$ is a subspace iff one of them is contained in the other.

The *orthocomplement* P^\perp of any subspace P is such that $P \vee P^\perp = \mathfrak{K}$, $P \wedge P^\perp = 0$, $(P^\perp)^\perp = P$, and $P \leq Q$ implies $Q^\perp \leq P^\perp$. Two subspaces P and Q are *orthogonal*, $P \perp Q$, iff $P \leq Q^\perp$.

We can quite naturally define QL as a formal logic on $L(\mathfrak{K})$. First we start with a set of logical vocabulary $\{\vee_{QL}, \&, \sim\}$, and take the propositions to be handled by QL to be all experimental propositions, x_p , which may be asked of a system, of the form ‘will the system pass a test for some possible state P with probability 1?’ (Bacciagaluppi, 2009, 9) A function $f: x_i \rightarrow L(\mathfrak{K})$ then puts the set of these propositions x_i into bijective correspondence with $L(\mathfrak{K})$. For each proposition $x_p, x_q \in x_i$, and subspaces $P, Q \in L(\mathfrak{K})$,

$$\begin{aligned} f(x_p \& x_q) &\text{ iff } f(x_p) \wedge f(x_q) = P \wedge Q \\ f(x_p \vee_{QL} x_q) &\text{ iff } f(x_p) \vee f(x_q) = P \vee Q \\ f(\sim x_p) &\text{ iff } [f(x_p)]^\perp = P^\perp \end{aligned}$$

Clearly, ‘&’, ‘ \vee_{QL} ’ and ‘ \sim ’ parallel the meet (\wedge), join (\vee) and orthocomplement ($^\perp$) operations on $L(\mathfrak{K})$.

Lastly,⁹ I define logical consequence as:

$$x_p \models_{QL} x_q \text{ iff } f(x_p) \leq f(x_q) = P \leq Q$$

3.2 The Status of CON

With QL set up, I return to the issue raised in §1. Recall the empiricist claim: QL, based off the structure of QM, apparently shows that CON is false. Consider QL’s equivalent of CON:

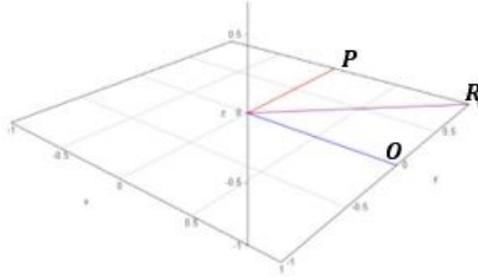
$$(\text{CON}^*): x_R \& (x_P \vee_{QL} x_Q) \leftrightarrow (x_R \& x_P) \vee_{QL} (x_R \& x_Q)$$

This holds iff:

$$(\text{CON}^\dagger): R \wedge (P \vee Q) = (R \wedge P) \vee (R \wedge Q)$$

Suppose that P and Q are orthogonal, and $R = P + Q$:

⁹ I ignore ultrafilters – QL’s analogue for truth-assignment – and logical truth due to space constraints. Nothing I discuss turns on them.



Clearly, $(R \wedge P) = 0$ and $(R \wedge Q) = 0$, i.e. they only intersect at 0. Therefore, $0 \vee 0 = 0$ on the right-hand side of CON^\dagger . However, consider the left-hand side: the intersection of the plane containing P and Q , and the subspace R is clearly R itself, since the entirety of R is on the plane. Since $0 \neq R$, CON^\dagger is false. A fortiori, CON^* is false.

Objection: nothing so far shows that the classical CON , employing ‘and’ and ‘or’, has broken down. Rather, I merely demonstrated the falsehood of CON^* , using ‘&’ and ‘ \vee_{QL} ’, on a restricted class of *experimental propositions*. Thus Maudlin (2003, 491) complains that “quantum ‘logic’ isn’t *logic*, i.e. isn’t an account of conjunction and disjunction”. To show that CON^* ’s failure entails CON ’s failure from an empirical perspective, proponents of QL must show that QL is classical logic – we just got the logical behaviour of ‘or’ wrong.

I think this requires us to first claim that, in the context of experimental propositions, there is **(a)** no connective ‘or’ that is *meaningfully definable*, and **(b)** the best replacement for ‘or’ is ‘ \vee_{QL} ’. Furthermore, **(c)** we must show that the experimental propositions of QL exhaust the propositions about the world. In other words, the structure of QM must completely describe the world. Without **(c)**, then the proponent of classical logic can still claim that the world is *really* classical, and the non-classical nature of QL only arises in the context of measurements: the world alone still gives us classical logic. Given **(a)** – **(c)**, though, the proponent of QL can assert that there is no other way to ‘read off’ disjunction from the structure of the world without using ‘ \vee_{QL} ’. This, together with the empiricist assumption that logic is given by the world alone, justifies the claim that ‘or’ was *really* ‘ \vee_{QL} ’ all along: CON^* is *really* CON , and since CON^* is false, so is CON .

Within the context of experimental propositions, there is justification for **(a)**: there is no clear way to introduce ‘or’ within QM’s structure since there is, in general, no experimental proposition or subspace in \mathfrak{K} corresponding to the classical disjunction of P and Q (Bacciagaluppi, 2009, 19). Furthermore, the one special case where $P \cup Q$ is a subspace, viz. when one of the subspaces is contained in the other, can be interpreted in terms of the *span* of P and Q as well. Lastly, it is clear that the span of P and Q is widely used experimentally, in e.g. considering superposed states of P and Q . Thus, either there is no experimental proposition corresponding to $P \cup Q$, or $P \cup Q$ can be understood as the span of P and Q in the special case, which in turn applies generally in QM. This gives us reason to claim that we cannot even speak of the classical ‘or’ meaningfully in terms of experimental propositions.

Dickson (2001, 4) further argues for **(b)**, claiming that ‘ \vee_{QL} ’ is the only other plausible candidate for replacing our classical ‘or’, since ‘ \vee_{QL} ’ satisfies most of our constraints on ‘or’. It is worth looking at the logical behaviour of ‘ \vee_{QL} ’ to see its similarity to ‘or’. For example:

$$P \leq P \vee Q$$

$$Q \leq P \vee Q$$

Consequently:

$$x_P \vDash_{QL} x_P \vee_{QL} x_Q$$

$$x_Q \vDash_{QL} x_P \vee_{QL} x_Q$$

Notably, this is reminiscent of the introduction rules for ‘or’. Furthermore:

$$\text{If } x_P \vDash_{QL} x_R \text{ and } x_Q \vDash_{QL} x_R,$$

$$\text{then } x_P \vee_{QL} x_Q \vDash_{QL} x_R$$

This is also similar to the elimination rules for ‘or’. ‘ \vee_{QL} ’ thereby appears to behave like the classical ‘or’. Of course, ‘ \vee_{QL} ’ behaves differently in other contexts, notably CON.¹⁰ However, given **(a)**, ‘ \vee_{QL} ’ seems the closest substitute for our classical intuitions about disjunctions in the context of experimental propositions.

4 Two Interpretations: Quantum Logic as Global Logic?

(a) and **(b)** concludes that classical logic cannot be ‘read off’ the structure of experimental propositions in QM. However, what about **(c)** – do experimental propositions exhaust all propositions about the world? I argue that there are at least two ways¹¹ to understand the world-structure QM prescribes and QL’s experimental propositions: this suggests that philosophical claims based on QM are “highly dependent on the interpretational approach one adopts towards the theory”(Bacciagaluppi, 2009, 36-37).

4.1 Bohmian ‘Pilot-Wave’ Interpretation

Bohm’s ‘pilot-wave’ interpretation (BM) takes every particle to have determinate positions and trajectories. However, particles are guided by a ‘pilot-wave’ obeying the wave-function Ψ , causing Bohmian particles to evolve in a uniquely quantum fashion. This wave-function also generates a statistical distribution of the particles’ positions, $P = |\Psi|^2$. This set-up allows BM to uncontroversially satisfy the constraints of QM formalism, as introduced in §2, e.g. the Born rule, and recovers *all* empirical results of QM.

However, on BM’s view, QM formalism is merely *epistemic* in nature. As Bohm notes: “The use of statistics is [...] not inherent in the conceptual structure, but merely a consequence of our ignorance of the precise initial conditions of the particle” (Bohm, 1952, 171). QM formalism is simply an effective tool for us to calculate the properties of particles, given that the determinate but hidden, level of phenomena – particles with

¹⁰ For an in-depth analysis of the logical behavior of ‘ \vee_{QL} ’, see Humberstone (2011, 913-917).

¹¹ I leave out the ‘Copenhagen’ interpretation here due to space-constraints – accepting it would not harm our case anyway.

determinate positions/trajectories – postulated by BM lies beyond the reach of measurement. However, in BM, particles are *really* ontologically classical (Bacciagaluppi, 2009, 30-31).

Particularly, in the case of superpositions and ‘ \forall_{QL} ’: under BM, if a system is in a superposed state, then Ψ ‘pilots’ particles to two states with a frequency distribution obeying the Born rule. However, importantly, the particles themselves are either in ‘support’ of one state or another in the classical sense: “the [position/trajectory] configuration of the system is located only in one of these different components, and this is already a matter of classical logic” (Ibid, 31).

On this deeper level, particles are in some determinate position at any one time, and all other properties are further derived from position variables on BM’s view. The world is *fundamentally classical*, and CON remains true. The use of spans – and ‘ \forall_{QL} ’ – instead of classical union in QL reflects not the world, but our inability to access the level of hidden variables: the ‘non-classical’ nature of QL arises from our epistemic limitations.

It is thus inadmissible to claim that QL’s experimental propositions exhaust all propositions about the world. Experimental propositions reflect not the totality of the world, but the limits of our epistemic access to the world. QL is, under BM, merely a logic of measurements and cannot be taken to conclusively replace classical logic (and thereby falsify CON).

4.2 Many-Worlds Interpretation

Contrariwise, the *many-worlds interpretation* (MWI) claims that QM’s formalism, and the experimental propositions of QL, completely describes the universe. However, on this view, our ‘world’ is but one ‘branch’ of the universe.

Consider a measurement device ϕ which points *up* $|\uparrow_{\phi}\rangle$ when an electron is spin-up, points *down* $|\downarrow_{\phi}\rangle$ when an electron is spin-down, and points *nowhere* $|\emptyset_{\phi}\rangle$ when there is no electron. Furthermore, an observer, O , can likewise be considered a system: Suppose O observes ϕ pointing a certain direction when ϕ in fact points in that direction. Let $|\uparrow_O\rangle, |\downarrow_O\rangle$, and $|\emptyset_O\rangle$ represent these O -states. Given a system E of a spin $_x$ -1/2 electron prepared in a superposed state $a|+_E\rangle + b|-_E\rangle$, we can construct a composite system $E \otimes \phi \otimes O$. Thus, when O observes ϕ measuring E :

$$(a|+_E\rangle + b|-_E\rangle) \otimes |\emptyset_{\phi}\rangle \otimes |\emptyset_O\rangle \rightarrow a|+_E\rangle \otimes |\uparrow_{\phi}\rangle \otimes |\uparrow_O\rangle + b|-_E\rangle \otimes |\downarrow_{\phi}\rangle \otimes |\downarrow_O\rangle$$

However, instead of saying $a|+_E\rangle \otimes |\uparrow_{\phi}\rangle \otimes |\uparrow_O\rangle + b|-_E\rangle \otimes |\downarrow_{\phi}\rangle \otimes |\downarrow_O\rangle$ ‘collapses’ into $a|+_E\rangle \otimes |\uparrow_{\phi}\rangle \otimes |\uparrow_O\rangle$ or $b|-_E\rangle \otimes |\downarrow_{\phi}\rangle \otimes |\downarrow_O\rangle$ upon interaction with ϕ (per the projection postulate), MWI claims that the universe is in *both* states simultaneously – the universe remains *superposed*. This seems absurd since our measurements show *one* definite result. However, the phenomenology of measurement, and the projection postulate, is explained away in MWI by saying that *we*, as O , are entangled with one particular measurement outcome or another – from (one of) *our* perspective(s), only one outcome obtains. Furthermore, $a|+_E\rangle \otimes |\uparrow_{\phi}\rangle \otimes |\uparrow_O\rangle$ and $b|-_E\rangle \otimes |\downarrow_{\phi}\rangle \otimes |\downarrow_O\rangle$ rapidly *decohere*¹²

¹² For more on decoherence in MWI, see e.g. Wallace (2010, 2012).

following measurement, due to environmental interferences, and become *dynamically independent* of one another. For all practical purposes, then, there is only one definite state relevant to *us* ('one of' us). The other 'world' is effectively inaccessible.

Thus, MWI accounts for exactly the same empirical results as BM, and, as before, QL works as a logic of measurements. However, according to MWI, and unlike BM, the formalism of QM and the possible experimental propositions – corresponding to possible subspaces of \mathfrak{K} – are *not* just propositions about measurements or reflections of our epistemic limits: rather, they are *genuine* propositions about the universe.

Prime example: MWI takes superposed states as actual states of single particles, not stochastic distributions of classical particles into possible states per BM. On MWI, systems which are in superposed states stay so after measurement unlike BM, where particles are in either some determinate state or another. On MWI, each component state of the superposition *actually* obtains, albeit in dynamically independent 'worlds'. In considering the classical union of two states of a system, then, we must consider the span of the two states where we find their linear combination, i.e. the *actual* state of the universe. Hence, we see that propositions about the universe behave like the experimental propositions of QL in that they map onto the lattice-structure of $L(\mathfrak{K})$: QL under MWI *replaces* classical logic as the 'true' logic of the world.

Furthermore, MWI explains why classical logic has been so successful from our perspective: CON is validated by *our* 'world', which is decohered from other worlds (in everyday macroscopic scenarios) – only one of the quantum disjuncts obtain *from our perspective*. However, we were mistaken to think that our 'world' is all there is to the universe. Both quantum disjuncts really do obtain in the universe, and the universe is described completely by QM and the experimental propositions in QL. Thus **(c)** obtains, and we might claim that CON is really not validated by the world. Turning BM on its head, on MWI it is *classical logic* that arises from our epistemic limitations.

5 Empirical (Under)-Determination of Interpretation and Logic

I began by asking why logical truths are true. Hoping to avoid the conventionalist path, I turned to empiricism. However, §4 shows that the world alone, given by our best sciences, cannot give a decisive answer to whether experimental propositions exhaust all propositions about the world. Though BM and MWI are *empirically* equivalent, each reproducing QM's empirical results, each interpretation includes postulations about the world (hidden variables or dynamically independent worlds) beyond empirical reach. These interpretations also take different logics to be *the* universally true logic. This leads us to conclude that empirical evidence alone fails to determine the logic of the world: The 'true' logic, under empiricism, remains underdetermined.

I propose this situation leads back to *conventionalism*. Here, conventionalism is not the thesis that logic is 'true by meaning' or 'convention'. It makes no substantive claims about the truth-status of logical truths. Rather, this conventionalism is analogous to the situation for our universe's 'ultimate' space-time structure. It is generally agreed that *that* is conventional, in the sense that general relativity "allows for a wide variety of cosmological models but that, due to structure internal to the theory itself, does not allow us to determine which of these models best represents our universe" (Manchak,

2009, 53).

This applies for QM and its various interpretations: “no amount of evidence will ever compel us to embrace a particular scientific claim” (Ibid, 53) about QM’s interpretation. This is what I call *empirical conventionalism*, which is described by Sklar as such: “insofar as the two theories have the same predictive content with regard to the directly observable facts, they ought to be viewed as merely conventional alternatives to one another and not as genuinely alternative theories about the nature of the world” (Sklar, 2004, 958). In other words, QM formalism and its empirical results is in principle indifferent between interpretations.

This is old news in physics – many have been willing to ‘shut up and calculate’, ignoring interpretative questions precisely because of empirical conventionalism. What is new to us is the result that the choice of ‘true logic’ is also empirically conventional. No empirical evidence can determine whether QL or classical logic is true; this choice is arbitrary from an empirical perspective. Thus Belousek (2005, 673) concludes: “the ‘book of nature’ proves too ambiguous to be uniquely interpretable”.

Cushing’s solution is to go beyond empirical facts of the matter “to include factors such as fertility, beauty, coherence, naturalness and the like” (Cushing, 1993, 272). However, it is unclear what evidence can *empirically* settle the debate here, since all empirical results (ever) available to the two interpretations are equivalent. In any case, to rely on such extra-empirical factors is to give up on empiricism. Rather, logic choice is determined partly by human factors, which are at best intersubjective. To go down this route is to lose the objectivity of logic even on the empiricist view, yet it seems that, at least within QM, we must go down this route.

This distinction between unempirical and empirical facts can be further clarified with Putnam’s (1974, 33) distinction between two types of facts constraining what he calls total science:

(ICC) Internal Coherence Constraint: Science must cohere with *simplicity*, and agreement with *intuition*, and so on.

(ECC) External Coherence Constraint: Science must agree with *experimental checks*, i.e. empirical facts.

Here, an interpretation is chosen not only because it coheres with all possible empirical facts, viz. ECC, but also because of simplicity, intuitiveness, fecundity, etc., viz. ICC. Putnam suggests that ICC provides a further fact of the matter that decides between seemingly empirically conventional choices.

Two points: first, I think the acceptance of ICC simply makes the *unempirical* elements involved in interpretational choice more obvious. While something *can* be a determinate fact of the matter given such constraints, these constraints of simplicity, intuitiveness, etc., are exactly what appear to be intersubjective. Even if there could be a decisive fact of the matter given some choice of ICC, I am not sure we could ever find objective grounds for ICCs themselves. The choice of a determinate interpretation with ICC thus comes at a loss of objectivity.

Secondly, it is unclear whether there even *is* a fact of the matter under ICC whether BM or MWI is better. To me, at least, it is not apparent whether BM or MWI, presented above, is *simpler*, or more *intuitive*. Given the complicated nature of QM, and the technical and

conceptual apparatus required for both BM (hidden level of phenomena, distinct pilot-waves guiding quantum particles, non-locality) and MWI (a world of infinite ‘worlds’, decoherence as a rough-grained process), neither BM nor MWI obviously satisfies any given ICC (e.g. simplicity, etc.) better than the other. One is ultimately left to one’s metaphysical predilections.

In any case, the empiricist would have lost much in adopting ICC. Recall that empiricism aims to place logical truths on firmer grounds than logical conventionalism. Empiricism does so by appealing to the world because the relevant empirical facts determining a ‘true’ logic are intuitively objective in a way our linguistic conventions are not. However, even within empiricism, there is no determinate interpretational choice for QM. ECC does not suffice for any decision on the true world-structure and the ‘true’ logic; we must appeal to ICC, be it simplicity, intuition, or what-not. Regardless of the outcome of that debate, the resulting situation is certainly not objective as the choice seems to amount to something about *us*, as rational beings, as scientists, and so on. Consequently, the world *alone* has failed to give us the ‘true’ logic. Empiricism thus fails to obtain objectivity for logic, leading instead to empirical conventionalism. It is no longer clear whether this is more attractive than logical conventionalism.

6 Conclusion

Empiricists who want to recover the objectivity of logic by appealing to the world alone must recognize that our best theory of the world, QM, is underdetermined when it comes to the world-structure it prescribes. This entails that the ‘true’ logic is likewise empirically conventional – we have no empirical reason to think that CON (and classical logic) is true of the world or otherwise, because the true structure of the quantum world is unknown (indeed, unknowable). Adopting ICC to determine our ‘true’ logic only ameliorates this situation by basing our choice of logic on intersubjective – not quite objective – facts. Thus, empiricism, with its associated empirical conventionalism about logic, appears no better off than logical conventionalism in accounting for the objectivity of logical truths: something broadly conventional lurks.

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