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Inviting the vampire in: the relationship between value and thermodynamic depth

Clair Quentin and Ben Butler-Cole

PRE-PUBLICATION DRAFT

Abstract

We refute the objection raised against Marx's theory of value by Mirowski (i.e. that it is an internally inconsistent amalgam of the substance and social model of value) by identifying value insofar as it subsists between production and exchange with the property in statistical mechanics known as thermodynamic depth. In production, concrete labour time is converted into the thermodynamic depth embodied in commodities, and in exchange the thermodynamic depth of commodities is converted back into time again, albeit that at this point in the circuit the time into which it is converted is socially necessary labour time i.e. abstract labour. Consistently with the social model of value, increases in value can (as Mirowski points out) arise where changes in the conversion factor between time and thermodynamic depth take place between production and exchange, but (consistently with the substance model) the thermodynamic depth of commodities can only be increased in production.

1 Introduction

A simple theory of value (in essence a 'mercantilist' one [Magnusson, 2003, 46]) might equate quantities of value with sums of money, in the sense that things are 'worth' what we pay for them. When applied to business profits, however, this theory creates a paradox. A business creates its outputs by means of its inputs, and it pays for its inputs. If things are worth what we pay for them, then the price of its outputs should be the sum total of the price of its inputs. And yet, somehow, its outputs are (in general, supposing businesses to be generally profitable) worth more. It might be thought that the additional value comes from the work done to the inputs by the business in order to turn them into outputs, but that work is paid for in the form of wages just like any other input, and so is already accounted for. So where is the additional value coming from? Value theory in the classical tradition of political economy may be understood as an evolving approach to answering this conundrum on a macro scale.

In his book *More Heat than Light* historian of economics Philip Mirowski characterises the story of classical value theory up to and including Marx as a search for a labour-derived value 'substance', existing independently of money and conserved in exchange (1989). It has to be conserved in exchange because it is only on the premise that value is conserved in exchange that the conundrum of surplus arises. In this understanding of value, value is labour *physically embodied in commodities*, as if it were a substance generated by labour in production, imparted to commodities, and quantitatively conserved as it cycles back into the economy. Broadly speaking, this tradition solves the conundrum with an analysis whereby labour produces more value, in terms of commodities produced, than it uses up, in terms of wages or in terms of wage goods consumed.

This model has been memorably mocked as the 'phlogiston' theory of value (Clever, 2000, 118). It is here referred to as the 'substance' model of value. That label (and the invocation of 'phlogiston') should not be understood to limit the substance model to theories whereby an actual

physical substance of value is posited. What is posited, rather, is a physical property which is imparted in quantifiable form to commodities in production, and quantitatively conserved up to the point of exchange, so that the production of surplus as realised in exchange may be measured by reference to it. Not necessarily a quantity of something like an imaginary gas or a liquid, but at the very least a quantity that is physically embodied by a thing, in the way that length or mass or albedo are physically embodied by things.

It should be emphasised at the outset of the argument in this article that Marx's model of value was *not* this substance model. He expressly rejected the idea that the property of commodities that the act of exchange posits as commensurable was a physical property. 'No scientist to date has yet discovered what natural qualities make definite proportions of snuff, tobacco and paintings "equivalents" for one another', he wrote in Part Three of *Theories of Surplus Value* (1971, 130). No physical value substance was known to science and Marx's seemingly sarcastic tone strongly implies that the very idea of such a substance is preposterous.

Marx's model of value was, rather, what Mirowski refers to as a 'social' model of value, and we explore some of what that means in the section which follows. The core claim made in this article, however, is that Marx's observation about the state of science is out of date. There does exist a 'natural quality' that makes commodities "equivalents" for one another, and it has been recognised in the field of statistical mechanics since the late 20th century. That 'natural quality' (i.e. thermodynamic depth) is *not* value in the Marxian sense. But its formal relationship with value in the Marxian sense may be addressed, with potentially significant consequences for how value in the Marxian sense may be understood. We conduct an investigation to that end in this article.

If correct our conclusions have wide implications for a number of questions in relation to which there already exists extensive debate without the introduction of the concept of thermodynamic depth. Our purpose here, however, is primarily to introduce it. We leave for subsequent elaboration the implications of it vis-à-vis those existing debates.

2 The elapse of time between production and exchange

The paradigmatic instance of a 'social' model of value in Mirowski's analysis is the marginalist model that dominates in mainstream economics today. In marginalism value is synonymous with price, and prices are understood as coming into being at the intersection of market participants' marginal preference curves. Nothing is 'conserved' as if it were a physical value 'substance'; value just comes into being and vanishes again as a unique quantity existing at a single point in time as the social mechanism of the market brings about an exchange. In Marx's version of the social model of value that quantity is not a quantity of money but a quantity of 'abstract labour' – a 'social substance' brought into being by the mechanism of market exchange under the capitalist mode of production (1976, 149).

The concept of abstract labour is perhaps best understood by reference to fungibility (or, as Marx puts it in the Fowkes translation, divisibility into 'aliquot part[s]' [1976, 202]). In a sense, at the maximum level of abstraction, all commodities are fungible since they exchange for money, and with money one can buy other commodities. To effect this fungibility it is necessary to have the correct quantities of each, such as would attract the same amount of money (ibid, 127), but in principle, and assuming the correct quantities, any commodity can (via the medium of money) exchange for any other commodity. Fungibility at this level of abstraction reflects back on the labour that went into making the commodities. The specific prior *concrete* labour embodied in each commodity (which is relevant to that specific commodity's utility or desirability, making it a 'use-value' in Marx's schema [ibid, 126]) is irrelevant to its *quantifiable* equivalence with other commodities. For the purposes of exchange the labour it embodies is not that specific prior concrete labour but the fraction the commodity represents of the totality of prior social labour.

This totality, insofar as it must be treated as divisible into fungible fractions (which treatment reflects the forcible equivalence imposed on commodities by the mechanism of exchange) is what is referred to by Marx as ‘abstract’ labour (ibid, 128). Abstract labour is the ‘substance’ of value as Marx conceives of it (ibid, 131), meaning that the value of a commodity is the quantity of abstract labour embodied in it. The purpose of the concept of value in this context, it should be recalled, is not to be explanatory of price, but to serve as a universal quantifiable property of disparate commodities so that the source of surplus can be identified.

Marx proposes that abstract labour as it is embodied in commodities is to be measured in units of ‘socially necessary labour time’, which is ‘the labour required to produce any use-value under the conditions of production normal for a given society and with the average degree of skill and intensity of labour prevalent in that society’ (ibid, 129). A key feature of this metric, which reflects the logic of abstract labour, is that it quantifies value by reference to a notional totality of social labour as at exchange. Whatever the prior *concrete* labour, the act of exchange is what brings into being a notional totality of fungible prior labour, a fraction of which being the labour that would have been necessary to bring the commodity to the point of exchange in the quantity in question. ‘The value of a commodity is determined not by the quantity of labour actually objectified in it,’ Marx explains, ‘but by the quantity of living labour necessary to produce it’ (ibid, 676-7). Abstract labour is therefore a social and not a physical substance (ibid, 149); quantifiable, yes, and dependent for its existence on the prior concrete labour that went into the commodity, but brought into being by the exchange relations that exist under capitalism rather than by the physical process of production.

As we read him, Marx viewed the existence of abstract labour as a mere truism. This is perhaps most persuasively illustrated in his famous letter to Dr Kugelmann of 11 July 1868, in which he writes of the critical response to the recently published first volume of *Capital*:

The chatter about the need to prove the concept of value arises only from complete ignorance both of the subject under discussion and of the method of science. Every child knows that any nation that stopped working, not for a year, but let us say, just for a few weeks, would perish. And every child knows, too, that the amounts of products corresponding to the differing amounts of needs demand differing and quantitatively determined amounts of society’s aggregate labour. It is SELF-EVIDENT that this *necessity* of the *distribution* of social labour in specific proportions is certainly not abolished by the *specific form* of social production; it can only change *its form of manifestation*. Natural laws cannot be abolished at all (Marx and Engels, 2010, 68-69) (emphasis in source).

The ‘natural law’ to which Marx refers here is seemingly the laws of physics which prevents us from (for example) going back in time to allocate additional resources to some specific branch of production in order to increase the quantity of the resulting commodity which is available as at social distribution. The point he appears to be making in the passage above is that, while value is a social phenomenon under capitalism, all systems of social labour, and social distributions of the product of labour, are constrained by the indelible fact of past resource allocation at the point of social distribution.

His theory of value, he accordingly explains to Dr Kugelmann, is not some novel hypothesis that requires to be tested empirically; it is a restatement of a self-evident constraint arising from natural laws, albeit a context-specific statement of it which is applicable to the historical circumstance where the allocation of resources to branches of production and the distribution of their respective outputs is effected by the mechanism of exchange under the capitalist mode of production. We adopt this perspective. It is therefore (so we contend) central to the Marxian value-theoretical schema that, at the point of exchange, the allocation of resources to production is *in the past*. This perspective is shared by Mirowski, since it forms the basis for an anomaly he identifies in Marx’s

theory of value.

3 Mirowski's complaint: the Fooshire-Barshire bridge problem

Notwithstanding that Marx's model is of the social variety and not the substance variety, Mirowski complains that it is in fact a self-contradictory conflation of these two conflicting models (1989, 180). The basis of his complaint is that, while Marx advances a social model of value, it is nonetheless a *labour* theory of value, insofar as the answer it offers to the conundrum of surplus is that the additional value embodied in the outputs comes from the labour input creating more value than it consumes. And as we have seen, the labour takes place in the past (not necessarily, of course – in the case of some commodities the labour takes place at the point of consumption – but in the general case the labour takes place in the past). Marx is absolutely clear, however, that the quantity of value represented by a commodity at the point of exchange is the average amount of labour required to produce it *at that point in time*. This creates the contradiction whereby, with the varying of input values over time, value can appear to be created out of nothing, rather than deriving exclusively from labour. By way of illustration, consider the following scenario, which does not derive from Mirowski but illustrates in concrete terms his abstract complaint:

In the land of Foobar there exist two regions producing commodities in accordance with the capitalist mode, Fooshire and Barshire. They are in close proximity to each other but geologically dissimilar and separated by a deep and dangerous gorge. Because of the difference in their geologies, they are suitable for different food crops, foograin and barpulses. A bridge across the gorge enables easy trade between the territories, and so workers in both territories are accustomed to eating a balanced diet of foograin and barpulses. One day the bridge is destroyed by an earthquake and so the labour required to get foograin to Barshire, and barpulses to Fooshire, increases dramatically: an arduous journey down one side of the vertiginous gorge and back up the other is now required. Any Barshire baker with foograin acquired *prior* to the bridge collapse can now make foobread whose value would *include* that additional toil even though, upon acquisition, the value of the foograin only included the work of carrying it across the bridge. In a manner wholly self-contradictory for an analysis where value is said only to be created by human labour, the collapse of a bridge in an earthquake has *created* value.

If you ambush a Marxist with this problem (referred to in this article as 'the Fooshire-Barshire bridge problem'), they might say that it is not a big deal because prices fluctuate vis-à-vis value all the time. They might also point to important bodies of Marxian analysis which take in the very real possibility under actually existing capitalism that capital or infrastructure or wholesale quantities of commodities get destroyed. But these responses would be to misunderstand the technical content and theoretical nature of Mirowski's complaint: the flaw in Marx's reasoning that Mirowski identifies is that *value* – value in the precise sense that Marx himself describes in his variant of the social model of value, not a mere variation in price – can (anomalously) come out of nowhere.

If any reader remains unconvinced, the best way to understand it is to recognise it as the corollary of the phenomenon whereby, if the conditions of production improve between production and exchange, less value (as measured in socially necessary labour time) is realised for a given quantity of average labour deployed as an input. This is all very basic stuff – Marx explains it very clearly (1976, 677) – and it has been a mainstay of Marxian analysis of crisis for over a century. Mirowski's complaint follows from precisely the same logic but applied to the converse circumstance of a deterioration in conditions of production. Indeed Marx expressly acknowledges that this converse phenomenon takes place, with the consequence that the inconsistency that Mirowski identifies even arises on Marx's own articulation of his theory (1976, 318), albeit that (as discussed in greater detail in section on 'ergomochleusis' below) Marx himself does not provide a satisfactory answer to it.

4 Mirowski's complaint distinguished from a taxonomic intervention

Mirowski's complaint is a rigorous one to the effect that Marx's theory of value is internally inconsistent on a technical level. As elaborated above, he says that in its amalgamation of the social and the substance model Marx's schema produces results that contradict its premises. This is a slightly different stance from the interpretative one to the effect that Marx may simultaneously be read as a proponent of both the substance and the social model, but that claim has also been made. Heinrich (2004), for example, points out 'ambivalences' in Marx between "substantialist-naturalist theory of value" and a "monetary theory of value". Pitts (2021), goes further, taking these ambivalences in Marx's discussion of value to reveal a value-theorist of the social tendency at war with the scientifically retrograde and ahistorical substantialist within. And it is true that, while in his formal exposition it is absolutely clear that Marx is a value theorist of the social tendency, the sheer physicality of the self-valorization of value as imagined by him is hard to ignore.

To take as one illustration among the wealth of possible illustrations, consider how capital is imagined by Marx as 'dead labour which, vampire-like, lives only by sucking living labour, and lives the more, the more labour it sucks' (Marx, 1976, 342). Yes, images like this serve a literary purpose as viscerally compelling metaphors for a process which, on an analytical level, takes place in the sphere of social relations. But the 'vampire' here is also readily understood as value *as it is physically embodied in means of production*; physical matter which has been configured by past labour with the sole purpose of absorbing the present labour of those who operate it, thereby giving rise to further value (McNally, 2011, 132). With metaphors like this appearing in *Capital*, read alongside mention of the expenditure of 'human brain, nerves, muscles' (Marx, 1976, 164) and the 'reordering of matter' (ibid, 133), it is not surprising that many readers have interpreted Marx as working in the 'classical' or 'Ricardian' tradition that sees value as physically imparted to commodities by labour in the sphere of production (Saad-Filho, 1997).

That being the case, when Mirowski's complaint is referred to in the literature, it is generally by way of an introduction to a set of contrasting readings to be extracted from Marx rather than as a debunking requiring to be formally refuted (e.g. Saad-Filho, 1997; Pitts, 2021). Mirowski is by no means altogether ignored, but what seems to have been ignored is the technical content of the complaint. In the hands of Marxian commentators the complaint becomes little more than a taxonomic heuristic in the historiography of value-theory.

One possible reason for the technical content of Mirowski's complaint being ignored, at least within what might be referred to as 'classical' Marxism, may be that the grounds for the complaint are often simply assumed away on a formal level. This occurs as a side-effect of the dominant solutions to what is known as the 'transformation problem'. A very brief digression onto that topic is therefore (unfortunately) necessary. The 'transformation problem' is to do with capital ratios, which create the following difficulty for a labour theory of value: if surplus value comes from freshly-deployed labour then profit rates will be higher in less capital-intensive sectors, because more of the expenditure is on the element that creates the value, but this putative outcome does not conform to the observable facts. In the Marxian scheme the solution to this problem is that prices adjust in the market so that low-capital-intensity commodities sell at an undervalue and high-capital-intensity commodities sell at an overvalue. The problem comes when modelling an economy where the model includes this transformation from labour values to what is known as 'prices of production' and getting that modelling right is known as the transformation problem.

There are a number of proposed solutions to the transformation problem but the dominant solutions are what is known as 'simultaneous' solutions (see Hahnel, 2017, ch. 2 for a useful summary). In such a solution inputs and outputs are valued simultaneously. A number of variants exist but the details of how these systems work need not detain us; the key point for present purposes is that in simultaneous models there is no elapse of time during which an event such as the collapse of the

Fooshire-Barshire bridge is allowed to occur. It has been argued that simultaneity is not actually necessary to solve the transformation problem (Kliman, 2007); but once it is adopted as part of the solution the Fooshire-Barshire bridge problem also disappears, and so the inconsistency that Mirowski identifies is just assumed not to exist.

The problem with ignoring Mirowski's complaint on this basis, however, is that it constitutes a tacit acceptance that Marx's theory of value does operate, after all, a substance model. If we presuppose that value is carried unchanged through time, from (i) the moments of exchange when means of production were acquired, through (ii) the process of production where additional value is brought into being by the deployment of labour, to (iii) the subsequent moments of exchange where the resulting commodities are sold, then value is precisely the conserved property of commodities that the substance model posits. In order to solve the transformation problem, in other words, the dominant readings of Marx in the (as it were) 'classical' vein effectively let the physical substance of value in through the back door.

As already intimated there exists a contrasting body of readings that seeks to elaborate upon and deepen the specifically social aspect of Marx's theory of value, and (while traceable back to Rubin [1924]) it has been increasingly prevalent over the last half-century or so (Elson, 1979; de Vroey, 1981; Bellofiore, 1989; Postone, 1993; Murray, 2016; Pitts, 2018). It would not, of course, be possible to do justice to that contrasting body of readings in a one-paragraph summary but, broadly speaking, their overall burden is to emphasise the role of value as a historically contingent social mechanism which determines on a qualitative level the framework within which the exploitation of labour takes place under the capitalist mode of production. From the perspective of this contrasting body of readings, Mirowski's complaint would appear to be in the nature of a category error. Value does not trundle forwards in time from production to quantitative realisation *within* the circuit, but instead constitutes a system of relations and imperatives *governing* the circuit (or, at the very least, must be understood as an emergent property of the circuit as a whole).

One position seemingly held in common, therefore, between the readings which lets the substantialist model in through the back door, and the contrasting body of readings which expressly repudiates the substantialist reading, is that Mirowski's complaint need not be taken seriously as a debunking of Marx's theory of value.

We depart from this position by confronting the contradiction seemingly identified by Mirowski, treating it as a value-theoretical anomaly rather than a taxonomic intervention. As promised in the introduction to this article, we address the anomaly by identifying the 'natural quality' that makes commodities "equivalents" for one another'. That natural quality is (and we cannot emphasise this too strongly) *not* value in the Marxian schema, but its relationship to value in the Marxian schema may (so we contend) be set out using simple math. Accordingly, having in view that natural quality on the one hand and value as adumbrated by Marx on the other, the relationship between the two seemingly conflicting models of value can be formalised and (we contend) the conflict resolved. Rather than letting substantialism into the analysis through the back door, we therefore extend to it (in the manner truly befitting it, if it is indeed a vampire) a formal invitation.

We emphasise the formal nature of the reconciliation offered here between the two models Mirowski identifies because naturally there exists extensive debate between opposing readings of Marx as to how each should reconcile with the other on a conceptual or interpretative level. We are not making a contribution to that debate (or, if we are, it is indirect and unintended). The interpretation of Marx and conceptualisation of value which we present in this article are presented solely to assist the reader in understanding our solution to the technical problem Mirowski identifies.

5 The unique nature of the core claim being made in this article

The sphere of social relations within which value arises is of course not untethered from the physical universe (Schmidt, 2014; Moore, 2015). By the same token it is not a novelty to consider that value (in the broad, general sense of the word) is related to material phenomena: concrete labour is itself a material phenomenon, and other material phenomena have been posited as bearing a relation to value: energy, entropy and so on (Burkett, 2003). But our claim is of a different nature, and its distinctiveness needs to be carefully articulated in order to be properly understood. We are drawing attention to a unique physical property of commodities that behaves precisely like value in the substance model.

If one shows that a general physical process takes place at the point of production giving rise to something quantifiable – the expenditure of human energy in the performance of concrete labour, for example, (Carchedi, 2011, 60; see also Kicillof and Starosta, 2007; Bonefeld, 2010; Kicillof and Starosta, 2011; Bonefeld, 2011) or expenditure of energy more generally (Pirgmaier, 2021), or increase of entropy (Georgescu-Roegen, 1971) – it could be argued that that physical process bears some relation or another to the value that arises at the point of exchange. But none of these existing candidates actually behaves like value in the substance model. For that to be the case it would need to be physically embodied in the commodity, increased in the process of production, and (crucially) carried and quantitatively conserved to the point of exchange. Only then could it be an objective and commensurable value-type property possessed by all commodities, as the substance model posits.

This feature is absent in all existing attempts to connect value to some kind of physical corollary. The energy expended in production, whether by workers or more generally, is not a quantifiable property of the commodity which is physically carried with it to the point of exchange. On the contrary, it is largely dissipated into the environment around the production process in the form of heat. There is generally no trace of the energy expended in production anywhere near the commodity by the time it reaches the point of exchange, let alone some determinate quantity of it. By the same token the entropy arising from production processes is primarily to be found in waste heat (and other waste products). It is not a physical property of the commodity and *a fortiori* nor is it quantitatively conserved as such up to the point of exchange. And nor do the energy economics or entropy economics literatures go anywhere near the point of claiming that it is – those projects have other concerns. We are therefore making a claim of a unique and unprecedented nature. This is because our claim is that the quantity in question is a property which arises in production but is *still physically possessed by the commodity at the point of exchange*.

In his authoritative critique of the energy economics and entropy economics traditions Paul Burkett (2003) makes the point that value in the Marxian sense is such a powerful concept, in contrast to ‘physiocratic’ attempts to root value in a physical process or property, because (being a social rather than physical substance) the Marxian conception of value directly addresses the historically contingent relations of production under capitalism. We wholeheartedly agree. And it is precisely for that reason that the objective and commensurable value-type property proffered in this article, which arises in production and (crucially) is conserved to the point of exchange, is uniquely apt to be formally *distinguished* from value in the socially-determined Marxian sense, in order to address the anomaly identified by Mirowski. It alone conducts itself as value would if it were a physical as opposed to a social substance. Indeed (as we shall proceed to demonstrate) the ‘natural quality’ in question *is* value in the substance model.

6 Reorderedness

It was suggested above (recalling the ‘phlogiston’ mockery and Marx’s sarcasm regarding the tobacco, snuff and paintings) that it is counterintuitive to claim that the commensurability between

heterogeneous commodities which is posited by exchange under the capitalist mode of production might have some kind of physical corollary. But it is less counterintuitive to make such a claim if one does not go so far as to claim that the physical corollary is, like value, a specifically *quantitative* property of the commodity at the point of exchange. If we claim merely that a manufactured or transported commodity is, at the point of exchange, physically *distinguishable* from some previous state of its matter (for example its state prior to production or upon acquisition of the raw materials) then the claim becomes a truism. The claim is simply that, in production, *something* happens. And that truism has implications for how we understand abstract labour.

It will be recalled from the discussion above that what forces heterogeneous concrete labour into fungibility (and therefore what brings abstract labour – the social substance of value in the Marxian schema – into being) is the quantitative equivalence imposed on that concrete labour at exchange. But that quantitative equivalence requires that the labour be quantitatively predicated by the commodity at exchange. In a universe in which it was possible to click one's fingers and bring arbitrary quantities of commodities into being at will, or go back in time to allocate further resources to production, there would be no possibility of abstract labour because no determinate quantity of past resources would be needed in order for the commodities to manifest in specific quantities at the point of exchange. And if the quantities are indeterminate they can't be forced into fungibility. There is no meaningful sense in which twenty yards of linen is equal to one coat if one coat could equally be five yards of linen, or fifty. But in our universe, the physical presence of a quantity of commodities at exchange *predicates* matter undergoing some process of rearrangement, with a quantity of resources allocated to that rearrangement which is now indelibly fixed in the past. And it is only by virtue of the fact that those quantities are fixed in the past that they are forced into fungibility by exchange.

This feature of abstract labour means that the physicality of the commodity at the point at which exchange takes place functions as the material vector of value. And it does so whether we are operating the substance model of value or the social model. If we obtain some foograin and bake a loaf of foobread in Barshire and then the Fooshire-Barshire bridge collapses before we sell it, we could (in accordance with the substance model) say that the loaf of bread still only embodies the smaller quantity of bridge-crossing labour, or (alongside Marx, operating the social model) we could say that it now embodies the additional toil of going down and then up the sides of the gorge. In the social model the past that is predicated is not (as with the substance model) the past that actually took place; it is, rather, the past implied by present conditions of production. Indeed this is the key difference between the two models for the purposes of Mirowski's complaint. But either way the model can only be applied because the physicality of the bread here, now, necessarily predicates some quantity of past labour.

We call that physicality of the commodity at the point at which exchange takes place, insofar as that physicality necessarily predicates prior resources allocated to its production (whether actual prior resources, or prior resources implied by reference to present conditions of production), its 'reorderedness'. The concrete processes which bring about reorderedness include all forms of resource extraction, agriculture, processing, manufacture, assembly, packaging, transportation and delivery. Any process, in fact, which is materially implicated in the 'reordering of physical matter' (Marx, 1976, 133)¹ which is required to bring the commodity, in the form in which it is subject to exchange, to the point of exchange. The 'reordering' of physical matter in production can take place on any level from the subatomic to the world-spanning. And that reorderedness is something which by definition commodities carry with them to the point of exchange. The commodity possesses its reorderedness at the point of exchange because it is what it is, where it is, at that point

¹ The phrasing comes from a quotation from Verri, 1771: 'Tutti i fenomeni dell'universo sieno essi prodotti dalla mano dell'uomo, ovvero dalle universali leggi della Fisica non ci danno idea di attuale creazione, ma unicamente di una modificazione della materia'.

in time. And (recalling the exposition of abstract labour above) exchange is how that reorderedness precipitates as a quantity of socially necessary labour time under the capitalist mode of production.

7 Introducing thermodynamic depth

Absent quantity, then, reorderedness as a material vector for value presents (so we argue in the foregoing section) as a mere truism, agnostic as between the substance and the social models of value. As well as being susceptible to precipitation as a quantity of socially necessary labour time by reference to exchange under the capitalist mode of production, however, reorderedness is also a quantifiable property of physical objects in and of itself. The physical property of things that this reorderedness corresponds to is the quantity in statistical mechanics known as thermodynamic depth (Lloyd and Pagels, 1988; Crutchfield and Shalizi, 1999; Lloyd, 2006).

Thermodynamic depth is a measure of complexity. But ‘complexity’ is not something that has a fixed scientific meaning; it can be defined any number of ways and what is actually being measured when you measure it depends on how you define it. Consider the difference between a blueprint and a recipe. They both give you comprehensive information about a thing, but in different ways that take different shortcuts: a blueprint does not tell you how to make a thing and a recipe does not provide you with a description of a thing. Generally speaking, you would expect a complex thing to have both an intricate blueprint and a long recipe, and a simple thing to have both a straightforward blueprint and a short recipe. It would follow, then, that a measure of the amount of space taken up by a thing’s blueprint, or by or its recipe, might be a measure of its complexity. But because blueprints and recipes take different shortcuts to describe a thing, those would be two different measures of complexity. It is possible to imagine a thing which is relatively intricate even though it can be made in a few steps, and by the same token it is possible to imagine a thing which is relatively straightforward even though it requires a greater number of steps. Scrambled egg, for example, is a homogeneous substance, but it takes a greater number of steps to prepare than a fried egg (because of the mixing of white and yolk), even though a fried egg (with its differentiation between white and yolk) is a more complex structure.

Thermodynamic depth is a measure of the complexity of a state of matter which is analogous to a measure of the length of its recipe, as opposed to the intricacy of its blueprint. The recipe should be understood not as a set of instructions external to matter, however, but as something possessed by the matter itself as a physical property. This is because thermodynamic depth is a concept from a branch of physics which views the state of matter as akin to information, in the sense that the location and state of matter *is* information about its location and state. Thermodynamic depth is a measure of a quantity of such information, but (crucially) it is not the entirety of the information possessed by the matter in question. It is a quantity of a specific subcategory of its information.

By way of background, a chaotic state of matter may be understood to contain a lot of information (i.e. information represented by the location and state of each particle), but this information is not useful; it is just (as it were) white noise. That being the case, it is possible to distinguish *useful* information as being antithetical to this abundant but meaningless information. ‘Useful’ information here does not mean information that is useful to humans – it means information that is salient for the purposes of a thing coming into being. To illustrate: to make a brick you do not need to tell causality where each of its clay particles goes. They can come in any arbitrary order, just as the heat which dissipates from the kiln when the brick is fired can create whatever arbitrary convection patterns it likes. But you very much do need to tell causality that a brick is a rigid oblong with flat sides. Or, to put the point in a way which more closely resembles thermodynamic depth as it is technically defined, you need to constrain the possible configurations of the matter of the brick to the ones where it possesses those properties.

The thermodynamic depth of a given state of matter is a quantity of this useful, non-chaotic kind of

information. Specifically, it is the quantity of that information that is required in order to constrain that state of matter in question to what it is, rather than some other state of matter, leaving out of account the non-useful chaotic information that it might possess. For technical reasons to do with how it is defined (essentially, as the difference between two different quantities of entropy), the unit of its measurement is joules per kelvin.

8 Thermodynamic depth and production

Production imparts thermodynamic depth to things. Taking the example of the brick from the previous section, if you take some clay, shape it into an oblong with flat sides, and fire it, you are giving rise to huge amounts of information that is not useful (the location of each clay particle; the convection patterns of the air from the kiln) but you are also imparting to it the information that it is a rigid oblong with flat sides. To do so is to increase its thermodynamic depth.

A crucial feature of thermodynamic depth for our purposes is that it is additive as regards process i.e. the thermodynamic depth of state C as compared to state A, having passed through intermediate state B, is equal to the thermodynamic depth of state C as compared to state B plus the thermodynamic depth of state B as compared to state A (Lloyd and Pagels, 1988, 187). This additive feature of thermodynamic depth means that (like value in the substance model, and in contrast to energy or entropy) the thermodynamic depth imparted to commodities in production is carried by commodities in conserved form all the way up to the point of exchange. The brick still has the information that it is a rigid oblong with flat sides when you sell it.

There is more, however. The identity noted above between states of matter and information, and the distinction drawn above between chaotic and ‘useful’ information, should be recalled. When workers operate means of production (whether it be button-pushing on highly sophisticated machinery, or the pushing of a wheelbarrow), they are physically imparting to the commodity thereby produced the entirety of the ‘useful’ information about its consequent state or location *qua* commodity, insofar as that information is not already provided by the means of production in an inert state. Indeed, precisely as with value in the Marxian understanding, additional thermodynamic depth is something that *only* labour can add to commodities. ‘Machinery’, wrote Marx, ‘creates no new value, but yields up its own value to the product it serves to beget’ (1976, 509; see also 1976; 312), and the same is true of thermodynamic depth in the system of commodities.

To illustrate, suppose by way of a thought experiment a machine which automatically converts homogeneous (i.e. low-complexity, low-depth) raw material, contained in a hopper which feeds it, into complex high-depth widgets. Suppose also that the hopper contains the precise amount of raw material the machine can convert into widgets before being worn out and requiring to be replaced. Further, suppose that the machine has a single control – an ‘on’ button which sets it in motion processing the raw material into widgets. *Prima facie* it may be supposed that the complexity in the widgets is imparted by the machine and not by the simple labour of switching it on.

Prior to the pressing of that button, however, the system already contains within it the useful information contained in the subsequent complex widgets, notwithstanding that the raw material is simple and homogeneous, since the machine’s already existing functionality is to produce those complex widgets. The complexity to be embodied in the widgets – i.e. the information constraint to be imposed on them – is therefore already encoded within the machine, and forms part of the system state before the machine is switched on. Once the button is pressed, that information constraint is imposed on the widgets, and once the raw material has run out, and the machine has expired, there is no more such information constraint to impose – all that is left of it is what is possessed by the widgets. The prior state is homogenous raw material plus the information in the machine, and the subsequent state is the widgets containing that information, and an information-depleted machine. The only *additional* information in the overall system in its subsequent state, as

compared to its prior state, is the information that the change in system state has occurred. And this is information which is imparted by the labour of pressing the 'on' button.²

Applying this thought experiment to the more realistic example of the brick, the functionality of the kiln already contains within it the information required to constrain the possible configurations of the matter of the brick to the configurations where it is rigid. But the only way to impart to a particular mass of clay the information that it is now rigid is to perform the labour of firing it. Looking back to how means of production are themselves produced, furthermore, the information that bricks are rigid (inherent in the functionality of the kiln) is imparted to the kiln by the labour of constructing it. We have said that the additive nature of thermodynamic depth means that it is carried to the point of exchange, but in fact (being additive) it is carried beyond exchange to the next stage of production. If you buy a kiln, the information that bricks are rigid, which was imparted to it in production, is still there at the point of exchange, and additionally that information is still possessed by the kiln when it subsequently re-enters the circuit as means of production. Indeed that is what makes it serve as such, imparting the information to specific masses of clay that they are now rigid, by virtue of the additional labour involved in firing them. And it continues to be able to impart that information until it is so degraded by use that it no longer functions, and therefore no longer itself contains the information that bricks are rigid.

This additive property of thermodynamic depth, understood as a quantity of 'useful' information embodied in commodities, therefore maps precisely onto corresponding behaviour on the part of value in the substance model. Value in the substance model is embodied in the kiln by the labour of making it, is carried by the kiln to the point of exchange, and is then transferred to bricks by dint of the labour of operating the kiln, along with additional value arising from that labour (this is the process which, if he were to be read as a substantialist, Marx would be describing in chapter 8 of *Capital*). And the resulting increased value is carried by the bricks to the point of exchange, and so on.

Indeed, from the perspective of a purely substantialist reading of Marx (which, to emphasise, we do not here advocate), thermodynamic depth is conceptually on all fours with value. This is because it doesn't merely exist as a property possessed by commodities which behaves like value in the substance model, it is (in principle at least) *quantifiable* as such. Any object possesses a determinate amount of thermodynamic depth, and any actually existing commodity at the point of exchange possesses a determinate amount of thermodynamic depth which is referable to the production processes that it has undergone in order for it to be in that state, at that location, at that point in time. Lloyd estimates that the thermodynamic depth of the entire universe is 10^{69} joules per kelvin (Lloyd 2006, 193).³ A certain amount of that depth is referable to the aggregate alteration of the state of matter represented by the commodities in circulation at any given moment, and a certain amount of that depth is possessed by any specific unit of a commodity as it arrives at the point of exchange. The state of matter represented by any commodity at exchange is the result of cycle after cumulative cycle of human labour constraining the possible states of matter to states possessing certain properties, and the degree to which that generalised phenomenon has taken place is a quantitative property of the commodity.

The observation on Marx's part that '[n]o scientist to date has yet discovered what natural qualities make definite proportions of snuff, tobacco and paintings "equivalents" for one another' is simply no longer true and has not been true since Lloyd and Pagels published their paper introducing the

² It is not, of course, the case that the widget machine after it ceases to be capable of producing widgets loses all thermodynamic depth. But the thermodynamic depth that is ultimately of interest here is that possessed by the system state at the point of exchange. The depth possessed by means of production so useless that neither it nor anything that it might hypothetically produce is going to be subject to subsequent exchange therefore falls out of the system state altogether.

³ Lloyd gives his estimate measured in bits and we have converted it to joules per kelvin (entropy is a variable in information theory as well as in thermodynamics).

concept of thermodynamic depth. The generalised reorderedness that is the material vector of value in the Marxian scheme, to be *socially* quantified as the value embodied by a commodity at the point of exchange (as to which see the foregoing section), also exists as a *physical* quantity in its own right; a quantity that is now known to science after all – the quantity that is thermodynamic depth. Thermodynamic depth is the objective and commensurable value-type quantity of which the capitalist mode of production gives rise to a physical surplus. It is to the relation between these two measures of surplus,⁴ the social and the physical one, that we now turn.

9 Ergomochleusis

The reorderedness of a commodity at the point of exchange under the capitalist mode of production exists, then, in two measures. It is possessed by commodities at the point of exchange (1) as a socially determined quantity (its value) functional upon the exchange of commodities as a totality, and (2) as a physical quantity (its thermodynamic depth), functional upon the path-dependent physical state of matter they represent. Logically it must follow that, at any given point in the evolution of conditions of production under capitalism, there will be a conversion factor between the physical reorderedness of matter generated under the capitalist mode of production, and exchange-quantified reorderedness measured in socially necessary labour time. This conversion factor, if converting from value to thermodynamic depth, would be measured in joules per kelvin per worker-second of socially necessary labour time. It would be equal to the amount of reorderedness produced by one second of average labour under prevailing conditions of production.

We call that conversion factor the prevailing ‘ergomochleusis’ of capital. ‘Ergomochleusis’ is a neologism coined here for this purpose. It derives from the ancient Greek ‘ἔργον’ meaning ‘labour’ and ‘μόχλευσις’ meaning ‘leverage’, as it may be characterised as representing the productive ‘leverage’ afforded to labour by the means of production that are deployed under given conditions of production. As a property of the system as a whole it expresses the per-worker rate by which gross thermodynamic depth is accumulating.

To be clear, there is no suggestion here that value, or abstract labour, are in any sense ahistorical or physical. They are not – value is a socially determined quantity of abstract labour (which is a social substance), arising exclusively under the capitalist mode of production. The claim is that the material vector of value, i.e. reorderedness in and of itself, which lacks quantity *as value* because it is lacking the social element of value’s ontology, nonetheless has quantity in its own right – and that quantity *is* ahistorical and physical. And that there must therefore be, in principle, under any given conditions of capitalist production, a conversion factor between the two.

One reason that this convertability between social and physical quantities of reorderedness is analytically useful is because it helps us solve the Fooshire-Barshire bridge problem. In abstract terms the problem illustrated by reference to the Fooshire/Barshire thought experiment is the problem that external events (like the collapse of the Fooshire/Barshire bridge or, to use the example that Marx himself entertained, the failure of a harvest [1976, 318]) can increase the amount of socially necessary labour time necessary to produce a commodity *after a capitalist has acquired the inputs necessary to produce that commodity*. The reason this is a problem is because it runs directly counter to the entire premise of Marx’s theory of value, insofar as that theory is concerned (by definition, as to which see above) with value as something which only human labour can contribute. It is something which only human labour can contribute, and yet here it is, in the thought experiment set out above, being increased in a loaf of bread by the collapse of a nearby bridge.

Marx blithely says of this outcome ‘the change in value originates outside the process ... of production’, and so (seemingly) does not interfere with his theory. In other words, he channels his

⁴ However it is measured, surplus is of course (as adverted to in the introduction to this article) subject to the netting off of means of subsistence quantified by the same measure.

(alleged [Pitts, 2021]) inner substantialist, essentially claiming that the difference is that in the one case more of the physical substance of value is produced but in the other case it is not. But this is not analytically satisfactory. As Mirowski pointed out, either all value comes from human labour, or it is something determined at the point of exchange by reference to the conditions of production generally at that point in time. Some sort of further explanation is required if it is going to be both of these things. What, in other words, is so special about production?

The answer lies in the fact that reorderedness – the material vector of value – has a physical (ahistorical) quantity as well as a socially determined one under the capitalist mode of production. And that physical quantity – i.e. the thermodynamic depth of commodities – cannot be increased except in production. And so, while the quantity of value is socially determined at exchange and can therefore be brought into being by a change in the ergomochleusis of capital, there is an ontological distinctness to an increase in value at the point of exchange which is specifically referable to production of more thermodynamic depth.

10 The formal relation between value and thermodynamic depth

Our argument is set out formally in this section. Readers who would like to follow the argument without engaging in the math are invited to skip to the final paragraph of the section, which summarises the key points in narrative form.

We postulate that the value of a commodity (V) is proportional to the thermodynamic depth of that commodity (D) relative to some arbitrary baseline. The ergomochleusis (ε) expresses the proportionality between value and depth as a quantity of depth per period of socially necessary labour time, so

$$V = (1 / \varepsilon) D.$$

(In this exposition we shall use subscripts to distinguish between the thermodynamic depths of different commodities, their value, and the prevailing ergomochleusis at different points of exchange.)

A given commodity at a specific point in time and space has a fixed thermodynamic depth. At the point of exchange the value of that commodity is determined not only by the depth, but also by the average conditions of production prevailing at the time of that exchange and may therefore vary between exchanges involving that commodity.

Since D is fixed, but V may vary between exchanges, we see that ε must vary according to the prevailing average conditions of production. We identify ε with the ergomochleusis possessed by the conditions of production prevailing at the point of exchange.

First we consider a simplified case where no additional labour is performed between exchanges and so the commodity is of fixed depth D_c . (We consider this simplified case in which no production takes place solely as a starting point for introducing the production element to the formal exposition, which we will proceed to do in a subsequent step.) In this simplified case the commodity just partakes in two different exchanges (one prior, labelled p , and one subsequent, labelled s). The expressions for the value at those exchanges are

$$V_p = D_c / \varepsilon_p \text{ and}$$

$$V_s = D_c / \varepsilon_s.$$

And so

$$V_s = (\varepsilon_p / \varepsilon_s) V_p.$$

Therefore, if the ergomochleusis of the average conditions of production increases between exchanges (that is $\varepsilon_p < \varepsilon_s$), the value of the commodity will decrease ($V_s < V_p$). By the same token,

if the ergomochleusis decreases then the value of the commodity will increase.

Further, as explored above, we postulate that the thermodynamic depth that inheres in a commodity consists entirely of that derived from the means of production and that contributed by labour during the production process. We now therefore consider a case where labour is performed between exchanges (the prior exchange being the acquisition of means of production). The means of production may be supposed to be entirely used up in this case or, alternatively, ‘means of production’ here refers to means of production to the extent its value is transferred to the commodity.

So, for the output commodity oc , means of production mp , and labour l

$$D_{oc} = D_{mp} + D_l.$$

But, by the relation above,

$$V_{oc} = D_{oc} / \varepsilon_s \text{ and}$$

$$V_{mp} = D_{mp} / \varepsilon_p.$$

And so

$$\begin{aligned} V_{oc} &= (D_{mp} + D_l) / \varepsilon_s \\ &= (V_{mp} \varepsilon_p + D_l) / \varepsilon_s \\ &= V_{mp} - V_{mp} + (\varepsilon_p / \varepsilon_s) V_{mp} + D_l / \varepsilon_s \\ &= V_{mp} + D_l / \varepsilon_s + (\varepsilon_p / \varepsilon_s - 1) V_{mp}. \end{aligned}$$

We see, then, that the value of the output commodity has three components: firstly, the value derived from means of production, V_{mp} , secondly a term, D_l / ε_s , which encapsulates the contribution to the value made by labour and thirdly a term which adds or subtracts a fraction of the value of the means of production. Note that the expression above shows that the operant ergomochleusis for determining the value contributed by labour is that which obtains at the point of subsequent exchange (ε_s), not that which obtained when the means of production were acquired.

Rather than simply being the sum of the value derived from the means of production and a quantity of additional value contributed by labour during production, this analysis demonstrates that there is an additional contribution $(\varepsilon_p / \varepsilon_s - 1) V_{mp}$. If the ergomochleusis has increased between the prior and subsequent exchanges then $\varepsilon_p / \varepsilon_s$ is less than one and the whole term is therefore negative, decreasing the total value of the output commodity. If the ergomochleusis has decreased, however, then $\varepsilon_p / \varepsilon_s$ is more than one and the term is positive.

This relationship is of course a phenomenon Marxists are familiar with. As already noted, improvements in technology have the consequence that less value is realised in exchange from a given amount of labour. Equally, more value may be realised in exchange as a result of infrastructure degradation such as (as in the Fooshire/Barshire scenario) the collapse of a bridge.

Our analysis reconciles the substance model of value with the social model of value (at least as they are characterised by Mirowski) by showing that the correct expression for the value of a commodity contains a term which represents the amount of physical value ‘substance’ produced by labour, and a term which represents the adjustment needed to reflect any changes in the average conditions of production since the means of production were acquired.

Note that where the ergomochleusis does not change between the prior and subsequent exchanges, i.e. in the limit where $\varepsilon_s = \varepsilon_p$, the adjustment term vanishes:

$$V_{oc} = V_{mp} + D_l / \varepsilon_s.$$

In this case, *and in this case only*, the value of the output commodity naturally decomposes into terms representing simply that derived from means of production and that contributed by labour, and one may justifiably write

$$V_{oc} = V_{mp} + V_l.$$

This case, i.e. the *special* case where the ergomochleusis does not change between the prior and subsequent exchanges, is the case which is assumed by simultaneity-based solutions to the transformation problem to be the *general* case.

In summary then, the value of a commodity at the point of exchange is *only* equal to the value imparted to it in production by means of production and labour (as both the substance model of value and simultaneity-based solutions to the transformation problem contend) in the specific circumstances where there is no change in prevailing conditions of production between production and exchange. But a property corresponding to value in the substance model (i.e. thermodynamic depth) is nonetheless carried from production to exchange in determinate quantities. The possibility of a change in prevailing conditions of production, i.e. a change in the conversion rate between average labour time and thermodynamic depth, may therefore be incorporated into the determination of value by means of an adjustment referable to the new conversion rate. On the level of detail, the way that adjustment functions is by way of the addition or subtraction of a fraction of the value derived from means of production.

11 Conclusions

So the ‘phlogiston’ of value exists after all and it is the thermodynamic depth of commodities. What, then is the role of value in the social model? Should we abandon the concept and analyse capitalism by reference to circuits of thermodynamic depth? The answer is emphatically that we should not. Capitalism is a social system, and it is driven forward by the fact that it is mediated by money, and money is a form taken by value in the social model, not by reorderedness. The thermodynamic depth of commodities is, in and of itself, simply an inert physical quantity like length or mass or albedo, and no-one is motivated to generate a surplus of it. Capitalism is driven forward by the systemic need on the part of *value* to create more of itself. It does not care whether it does so by dint of an increase in the quantity of some material vector, or by dint of a change in the conversion factor.

To put this point in concrete terms, using the Fooshire/Barshire scenario, if a Barshire baker buys up all the Foograin they can while the bridge is in place and then destroys the bridge by sabotage in the dead of night, that course of action would be just as congruent with value’s need to create more of itself as exploiting labour to bake Foobread in the ordinary course of a Barshire baker’s business. It is value that shapes the world we live in today, in all its ugliness and violence; not the physical reorderedness represented by commodities.

That said, we nonetheless offer the claim in this article as an advance in understanding how the social model of value speaks to production as a physical process. Value is (as Marx explains) a social substance determined by the mechanism of exchange in a manner historically contingent on the capitalist mode of production, but at the same time (as we have shown) value is a physical quantity of thermodynamic depth subject to a variable conversion factor (the ‘ergomochleusis’ i.e. the quantity of thermodynamic depth produced per average second of labour time under prevailing conditions of production). The material vector of value is the thermodynamic depth of commodities at the point of exchange and the social element under conditions of capitalist production provides the ergomochleusis by reference to which value itself is determined. In production, concrete labour time is converted into the thermodynamic depth embodied in commodities, and in exchange the thermodynamic depth of commodities is converted back into time again, albeit that at this point in the circuit (a) the time into which it is converted is socially necessary labour time i.e. abstract

labour, and (b) the conversion factor may have changed.

The social model of value elaborated upon by Marx and by Marxists, and all that model entails from the point of view of the critique of political economy, theory of crisis, and so on, flows from the existence of value in the form of abstract labour, which is a social substance, and nothing that we argue here is (we believe) inconsistent with that model. Our claim, however, is that during any elapse of time between concrete labour and exchange, the output of that labour (insofar as it shares with abstract labour the quality of being fungible) proceeds around the circuit of capital in the physical form of thermodynamic depth.

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