

This is a repository copy of *Economic imaginaries of the Anti-biosis : between 'economies of resistance' and the 'resistance of economies'*.

White Rose Research Online URL for this paper:
<https://eprints.whiterose.ac.uk/136361/>

Version: Published Version

Article:

Brown, Nicholas Gerard Francis orcid.org/0000-0002-4742-8595 and Nettleton, Sarah Joan orcid.org/0000-0002-5184-2764 (2018) *Economic imaginaries of the Anti-biosis : between 'economies of resistance' and the 'resistance of economies'*. Palgrave Communications.

<https://doi.org/10.1057/s41599-018-0178-5>

Reuse

This article is distributed under the terms of the Creative Commons Attribution (CC BY) licence. This licence allows you to distribute, remix, tweak, and build upon the work, even commercially, as long as you credit the authors for the original work. More information and the full terms of the licence here:
<https://creativecommons.org/licenses/>

Takedown

If you consider content in White Rose Research Online to be in breach of UK law, please notify us by emailing eprints@whiterose.ac.uk including the URL of the record and the reason for the withdrawal request.



ARTICLE

DOI: 10.1057/s41599-018-0178-5

OPEN

Economic imaginaries of the Anti-biosis: between 'economies of resistance' and the 'resistance of economies'

Nik Brown¹ & Sarah Nettleton¹

ABSTRACT This paper seeks to report on the way economic principles, formulae and discourse infiltrate biological research on antimicrobial resistance (AMR) in the life sciences. AMR, it can be argued, has become the basis for performing certain forms of 'economic imaginary'. Economic imaginaries are ways of projecting and materially restructuring economic and political orders through motifs, metaphors, images and practices. The paper contributes to critical social science and humanities research on the socio-economic underpinning of biological discourse. The performance of economy in this context can be seen to follow two key trajectories. The first trajectory, discussed at length in this paper, might be described as 'economies of resistance'. Here the language of market economics structures and frames microbiological explanations of bacterial resistance. This can be illustrated through, for example, biological theories of 'genetic capitalism' where capitalism itself is seen to furnish microbial life with modes of economic behaviour and conduct. 'Economies of resistance' are evidence of the naturalisation of socio-economic structures in expert understandings of AMR. The methodological basis of this paper lies in a historical genealogical investigation into the use of economic and market principles in contemporary microbiology. The paper reports on a corpus of published academic sources identified through the use of keywords, terms, expressions and metaphors linked to market economics. Search terms included, but were not limited to: 'trade-off', 'investment', 'market/s', 'competition', 'cooperation', 'economy', 'capital/ism' and 'socialist/ism', etc. 'Economies of resistance' complements a second distinct trajectory that can be seen to flow in the opposite direction from biology to economic politics (the 'resistance of economies'). Here, economic imaginaries of microbial life are redeployed in large-scale debates about the nature of economic life, about the future of the welfare state, industrial strategy, and about the politics of migration and race. 'Economies of resistance' and the 'resistance of economies' are not unrelated but, instead, they are mutually constituting dynamics in the co-production of AMR. In attempting to better understand this co-production, the paper draws upon literatures on the biopolitics of immunity in political philosophy and Science and Technology Studies (STS).

¹University of York, York, UK. Correspondence and requests for materials should be addressed to N.B. (email: nik.brown@york.ac.uk)

Introduction

Over the course of recent decades, the immune system has become the focus of concerted academic enquiry into the increasingly entangled relationships between economy and the biosciences. This is a recognised feature of broader life science markets and industries, and the translation of the immune system into new sources of biovalue. For example, the immune system has become a transformative object of modern economic activity in regenerative medicine (Waldby and Mitchell, 2006), allergy testing (Nettleton et al., 2009), the geopolitics of transplantation (Beck, 2011) and global infrastructural investment in stem cell banking (Brown et al., 2011; Brown and Williams, 2015). The immune system serves as a pervasive way of imagining and performing the self (Haraway, 1999), as well as markets and the varied forms taken by capital (Martin, 1994; Brown, 2018).

In this paper, we want to build on this avenue of enquiry to explore the relevance of an immunitary perspective to scientific and political debates about antimicrobial resistance (AMR). The context for our discussion is the apparently limitless capacity of microbial organisms to develop, through mutation and/or acquisition, resistant forms of immunity to the many chemotherapeutic compounds designed to keep them at bay. AMR registers a particular turn taking place in the politics of the bioeconomies, premised increasingly on biosecurity discourses of anticipatory pre-emption of a hostile microbial resurgence (Cooper, 2006). But, what we want to do here is also explore the way AMR has become the basis for performing certain forms of 'economic imaginary' (Jessop and Oosterlynck, 2008; Jessop, 2004) by projecting and restructuring economic and political orders.

We show below how the immunitary performance of economy in AMR can be seen to follow two key trajectories. The first we have called 'economies of resistance' in which principles of economy are borrowed into biological explanations of AMR. This is, for example, most clearly expressed in theories of 'genetic capitalism' in microbiology where capitalism itself is seen to provide or furnish microbial life with modes of economic behaviour and conduct. 'Economies of resistance' are evidence, we suggest, of the naturalisation of socio-economic structures in expert understandings of AMR. Another trajectory we have explored elsewhere (Brown and Nettleton, 2017) is concerned with the way microbial life is re-deployed in the large-scale reconfiguration of political agendas about the future of national economies, the public-private interface, and even migration and race. This can be expressed as the 'resistance of economies' and is empirically located in an analysis of high profile political interventions on AMR in the UK, spanning several decades into the present. 'Economies of resistance' and the 'resistance of economies' are not, we will suggest, unrelated but mutually co-constituting dynamics in the co-production of AMR. In other words, how we come to 'know and represent' AMR is, at the same time, a question of both biological and social ways of life and living (Jasanoff, 2004, p. 2; see also Chandler et al., 2016 and Landecker, 2016). Before exploring these two trajectories in more detail, we want to foreground our discussion through scholarship on immunity as a configuration of economy.

Brown et al. (2011) have written of the 'immunitary bioeconomy' and the 'capitalisation of immunity' whereby the immune system, its characteristics and properties, becomes the basis for new forms of commercialisation and trade. In this case, umbilical cord blood units, banked throughout the world (Brown and Williams, 2015) can be seen to extend the properties of what Roberto Esposito (2008) calls an 'immunitary paradigm'. Immunity here constitutes new forms of bioeconomic flow, circulation and exchange. Esposito writes of the immunitary paradigm as a developing biopolitical and historical juncture in which

biology, politics and economy have become steadily more intertwined. Building on this we want to show how both the science and politics of antimicrobial resistance operates as a vehicle for particular kinds of economic enterprise.

In a very similar way, Beck (2011) explored how bone marrow donation and transplantation disrupts nation-state borders, even those entangled in long-standing military hostility. The context for his thinking is post-colonial Cyprus, militarily bisected since the 1970s along Turkish and Greek-Cypriot ethnic lines. Nevertheless, donor registries of potential bone marrow donors cut across and increasingly disrupt these hostile settlements. Immunophenotyping can be seen to supersede and supplant ethnic identification, producing new forms of inter-ethnic association between Turkish and Greek donors and recipients. In this way, the bioeconomies of transplantation reconfigure economic and political-administrative entities and social movements, resulting in a transformative immunitary cosmopolitanism.

As we suggest above, the immune system can also be seen to become a medium for what Jessop and Oosterlynck (2008) have called 'economic imaginaries'. That is, immunity performs modes of imagining and projecting visions of economy which embody various moral values, norms and codes of behaviour. Economic imaginaries become attached to and articulated through cultural systems of knowledge, like immunology, virology and bacteriology, and institutions, like hospitals, financial institutions and educational establishments. In approaching AMR through the ideas of an 'economic imaginary' we acknowledge the semiotic and material dimensions of the biotic political economy. Economic imaginaries are performative, they guide the patterning of priorities and concerns. They establish '... how and why only some economic imaginaries among the many that circulate actually come to be selected and institutionalised...' (ibid., 1155). In what follows we outline just some of the broader features of this terrain before focussing more directly on AMR. We also want to explore AMR as an aspect of biopolitical life in which the immune system serves as a primary site of economic and cultural enterprise. Before discussing 'economies of resistance' in microbiology, it is worth briefly revisiting what we have called the 'resistance of economies' in politics and policy.

We have told some of this story elsewhere (Brown and Nettleton, 2017) but it is useful to sketch some elements of it here. The 'resistance of economies' counter-balances the crosscurrents between economy and biology found in the world of microbiology documented below. As we move from biology to the parallel world of politics and policy we have shown how AMR becomes a vehicle for economic strategies. It was possible to see this in the way the former British Prime Minister, David Cameron, in 2014, sketched out the dystopic prospects of a future 'return to the dark ages of medicine'. One of the reasons we found this of particular interest is because it echoes a previous intervention by one of Cameron's predecessors. In the mid-2000s, Michael Howard, the former leader of the British Conservatives, in opposition at the time, spoke of hospital infections (MRSA) as institutionally symptomatic of a nation and not national in decline under a Labour government.

Howard's rhetoric settled around the equally alarmist language of 'superbugs', and Britain as 'the sick man of Europe'. Britain could only be restored to health once again by a more strident return to the principles of Thatcherism, of the economic reformist logics of privatisation, the profit motive, internal markets and competition between public healthcare suppliers. A moral and biological crisis had broken out in the NHS. MRSA also melted easily into anxieties over crime and immigration (Wring, 2005). The Conservatives announced manifesto plans to impose the compulsory screening of migrants prior to departure from

their countries of origin, a biopolitics that positioned ‘immigrants as vectors of disease’ (Craig, 2007, p. 273).

For Cameron, almost exactly a decade later, the threat of being ‘cast back into the dark ages’ quickly gained traction in political and media commentary. The ‘dark ages’ sits in opposition to other temporal figurations including the ‘golden age of medicine’, ‘modern medicine’ and even ‘civilisation’ itself. The ‘dark ages’ reference reinvigorated political and policy attention and shifted AMR’s apocalyptic register (Nerlich and James, 2009; see also Crawford et al. 2008). The important point about both of these moments is the way they differently express the ‘resistance of economies’. Both are underpinned by the underlying logics of a neoliberal agenda and the promise of the market. Cameron points to ‘market failure’ and weakening profit incentives in the supply chain of antimicrobials, contentiously appointing the monetary economist Jim O’Neill to lead the new government review. Many of the preceding national and international government reports had attached far greater importance to surveillance, the stewardship of antimicrobials or ‘rational prescribing’ (reduction), together with the control of infections (hygiene) and better diagnostics (Department of Health, 2000). In both of these political moments, the biotic becomes the basis for ‘economic imaginaries’ (Jessop and Oosterlynck, 2008), for reconfiguring the role of consumers, advancing the privatisation of healthcare delivery, and more recently, incentivising pharmaceutical market motives. In this way, as Emily Martin (1994; 1997) has observed, the immune system becomes a vector for the political and moral economies of business, security, class and race.

In all of these differing accounts, immunity is always economically and politically idiosyncratic. That is, versions of immunity are specific to their context and times, naturalising political agendas and underpinned by changing distributions of agency and sometimes blame, guilt and responsibility. In what follows we bring these conversations to bear on what we call ‘economies of resistance’, the naturalisation of economic principles in the development of microbiological resistance. This complements directly the parallel process, discussed above, in which microbial behaviour is projected into the restructuring of political and economic life, a process we call the ‘resistance of economies’.

In documenting ‘economies of resistance’ we have undertaken a genealogical investigation into the history of economic and market principles in contemporary microbiology (Foucault, 1991). Our purpose has been to engage in the critical analysis of expert microbiological discourse, and its ‘regime of practices’ (ibid.) in order to question the seemingly self-evident nature of ideas that govern life. In this case, we want to locate ‘economies of resistance’ in their political, historical and cultural present. Here we are interested in the structuring of medico-expert knowledge through the power nexus of market discourse, and how it is that this becomes organised and sustained. Methodologically, we have identified a relevant and highly cited corpus of published academic sources that elaborate on the parallels and relationships between market economies and resistant bacterial ecologies. This has included tracking keywords, terms, expressions, metaphors and ideographs linked to market economics. Search terms included, but were not limited to, the following: ‘trade-off’, ‘investment’, ‘market/s’, ‘competition’, ‘cooperation’, ‘economy’, ‘capital/ism’ and ‘socialism’. We have also focussed our attention on the migration of a number of economic formulae and financial explanatory principles into microbiological discourse. This includes the Matthew effect, Zipf’s law and the Pareto principle (see below). There are thousands of sources in academic microbiology and related fields in which these themes are evident, either implicitly or more unequivocally. Our approach here has been to identify a sample of several hundred sources, which are

illustrative rather than representative, of ‘economies of resistance’. This, we hope, lays the foundation for a potentially wider and more ambitious future analysis of economic tropes in expert biological research on AMR.

Economies of resistance

One of the more explicit articulations of market economics in AMR centres on the discourse and theories of ‘genetic capitalism’ in microbiology. Here, capitalism itself is seen as the prototypical model *par excellence* for the behaviour of resistant bacterial strains selectively evolving to outcompete each other and their toxic market rivals. Capitalism, in this context, is more than a passing metaphor but instead becomes an explanatory theory with its own suite of prognostic propositions and hypotheses.

Baquero et al. (2003) place the concept of ‘genetic capitalism’ squarely in modern evolution theory, but also ranging eclectically across classical and modern sources including Aristotle, the philosophy of Solomon ibn-Gabirol, Darwin, Dawkins, Gould and others. Resistance is seen to accumulate in equal proportion to uninhibited flow where ‘... the best combinations for local survival increase in number, facilitating further adaptive possibilities, reflecting a kind of genetic capitalism’ (ibid., 547). Genetic capitalism situates AMR in foundational conceptual interactions between social and economic notions of agency and structure, action and form. ‘The source of life flows’ they write, ‘... because of the continuous interplay of matter (individuals) and form (order)’ (ibid.). Not untypically in the context of contemporary writing in evolutionary biology, what is or is not an ‘individual’ is far from straightforward. The ‘individual’ can be anything ‘with the potential to maintain, replicate, or reconstruct its self-identity’ they write. What defines the individual here shifts from its classic Darwinian meaning where the ‘... the finger of evolution operates within the selfish organism’ before turning to its later ‘Dawkinian sense’ in the ‘selfish gene’ (ibid.). The conception of individuality then progresses towards an ‘ultra-Darwinism’ where evolution occurs much more systemically at the ‘sub-and supraorganisational levels’. Notwithstanding market volatility, the purpose or objective of the ‘individual’ is here located in a biological naturalisation of the economic tendency towards order and the avoidance of chaos. ‘Nature’ itself is rendered ‘an ordering force’ operating according to self-equilibrating laws of market fundamentalism. They write of the inherent tendency for, all things being (un-)equal, the ‘rich to become richer’. ‘Individuals’ are seen to ‘fight’ for time (multiplication into the future) but also for space (colonisation). Modelling AMR through time and space is articulated as an investigation into the ‘protein universe’ of unending replication and adaptation.

Genetic capitalism also connects with more recent theories of complexity in both immunological and economic theory. In AMR, ‘...we can observe a hierarchical gradient from lower to higher complexity. Indeed, this hierarchical theory links evolutionary research with the science of complexity, reflecting an almost universal property of complex systems’ (ibid.). The interest here in complexity theory borrows upon significant intellectual forces, documented by Tauber (1998) and others, bubbling up in immunology and microbiology. Immune system theory is seen to move away from its static and binary mid-twentieth century framework, to one increasingly guided by the conceptions of ‘fluid’ dynamics and ‘emergence’, of the ‘network’ and ‘complexity’. Genetic capitalism illustrates the identification of, as Tauber put it, ‘...new kinds of models, perhaps most effectively described by nonlinear logic, complexity theory, and self-organisational precepts’ (ibid., 462).

In a follow-up article (Baquero 2004), genetic capitalism emphasises the ‘acquisitiveness’ of successful and highly dynamic

microbial strains able to absorb and accommodate advantageous genetic assets, or rather, 'pieces'. Acquisition is the basis for new forms of microbial wealth where, '...by analogy with capitalist societies, those organisms that have become rich by acquiring pieces have an increased probability of becoming richer and, therefore, of acquiring further pieces' (ibid., 510). Organisms here are seen to rival one another within the market space of local 'trading zones'. These may be clinics, wards or whole hospitals. Crucially, genetic capitalism reframes biotic spaces through metaphors of banks, banking, finance and investment. Clinical space is reconfigured becoming a depository of available bio-wealth to be borrowed, invested and traded by biotic shareholders. The hospital is a site in which a 'bank of adaptive pieces might be established in the local metagenome' (ibid.). Acquisition in theories of genetic capitalism borrows upon the market logics of economic monopolisation and institutionalised modes of asset-stripping or 'mergers and acquisitions'. Resistant strains may be seen to develop from the assimilation or consolidation of the traits of multiple genetic entities into that of a single organism. Acquisition, in the microbiological context, as in that of corporate law and practice, occurs through transfers in the ownership of 'genetic stock', assets or equity interests. It is hard not to be reminded here of Martin's attention to a flexibly dynamic immunity when Baquero writes of the way 'winner configurations' are seen to absorb and 'attract more adaptive advantages through genetic capitalism' (ibid.). And further, the way advantages result from fluid exposure within the flux of a 'broader range of interactions' (ibid.).

As in good business etiquette, mutations carry 'visiting cards' to be liberally distributed amongst microbial contacts and acquaintances. Business cards are subsequently collected together within the bacterial chromosome, which in turn 'facilitates further exchanges'. Much of the subsequent literature on genetic capitalism is littered with market and engineering-based theory where antibacterial assets are conceptualised as circulating through 'circuits' within 'the local evolutionary toolbox...acquiring new and potentially advantageous pieces' (Baquero, 2004). The metagenome of capital is a volatile and opportunistic space in which 'chance favours the prepared genome'. However, any strain establishing a successful monopoly position risks temporary states of 'bankruptcy' before 'stabilisation' is re-established and 'members' re-emerge in 'a new organisational format' (ibid.). Recombination and gene transfer in the highly complex interplay between traders results in, as Leavis later puts it '...a genetic subpopulation that is highly specialised for survival and spread in hospitals; this process is called 'genetic capitalism...'' (Leavis et al., 2006, p. 454; see also Willems et al., 2005). Another paper emphasises the powerful way in which a theory of genetic capitalism '...predicts [that] the most successful clones are also more likely to acquire MDR [multi-drug resistant] determinants and be selected under antibiotic pressure, hence being spread' (Juan et al., 2010, p. 474). It is also telling that this particular reference to genetic capitalism, like many others, occurs in the context of a discussion about the globalised biological flow of, in this case, '...internationally widespread (successful) *P. aeruginosa* clones...suggesting that the driver of this incipient MDR *P. aeruginosa* pandemic is a global spread of successful clones combined with the local acquisition of MDR determinants' (ibid.).

In the literature on antimicrobial resistance and in wider microbiology, genetic capitalism is often used interchangeably with the concept of the 'Matthew effect'. Like genetic capitalism, the use of the Matthew effect interweaves socio-economics and evolutionary theory into microbiological understanding. Here however, the concept of the Matthew effect has its origins in the functionalist sociology of R.K. Merton (1968). Here it is a distinctively sociological construct that now in the context of AMR

frames the tendency of resistant organisms to benefit from accumulated market advantage. Merton's coinage of the term is taken from the scriptural reference to the parable of the talents ('For unto every one that hath shall be given, and he shall have abundance'), or in economic parlance, 'the rich get richer'. In Merton's sociology of science, the term expresses the way credit and status amasses around those already prestigiously positioned to take advantage of reward. In AMR, microbiology can here be seen to draw on functionalist explanations of social selection to explain the natural and disproportionate relative advantage of some microbial strains over that of others.

A more recent editorial in *Nature* (Römling, 2013), entitled 'Bacterial communities as capitalist economies' describes the way the grouping of bacteria on surfaces 'reveals a 'rich-get-richer' mechanism' amplified in a 'positive feedback loop' (Zhao et al., 2013). What is important about some of the literature on, in this case, biofilm formation, is its focus on the 'individual' bacterial cell. Whilst much of microbiology is preoccupied with bacterial colonies and colonisation at the whole population level, other work centres on the sometimes mutually beneficial behaviour of single individuals. In documenting the attachment of cells to surfaces, the individual bacteria is seen 'exploring the surface and priming their environment for subsequent biofilm development' (Römling, 2013, p. 321). Successful colonising agents are seen to be highly selective and discriminatory. Bacteria purposefully search for and select such sites in a 'non-random manner', directing their attention to locations most frequently visited by other actors in the marketplace. Bacteria are understood to be mutually guided by 'a synergistic 'rich get richer' mechanism, in which cells go where other cells go most often' (ibid.). 'Elite' bacteria are those who leave more evidence of themselves at sites 'extremely rich in communally produced' traces left behind after being visited. It is this 'social structure' which is necessary for 'cooperative invasion'. Another source (Li et al., 2012) had previously described how microbial resistance comes to depend on 'just-in-time' bacterial responses to the environment. Here however, in addition to the Matthew effect, we now have 'Zipf's law', a mathematical probability distribution used to explain power differences. The editorial goes on to describe how it is that many 'self organised systems, including wealth distribution in capitalist economies, follow Zipf's law' (Römling, 2013). Without going into too much detail here, the linguist George Kingsley Zipf, in the first half of the twentieth century, pointed out how in any language system, as might be expected, a small number of words are used with disproportionately increasing frequency. That 'power frequency' results in languages exhibiting a lengthy 'tail' of underused or semi-redundant words, grammatical rules and expressions. The formula subsequently makes its way into economics and other disciplines to explain the apparently inevitable naturalness of almost any disproportionately unequal distribution (the possession of wealth in capitalist systems, internet traffic, city growth, etc). Here in the context of microbiological explanations for the monopolistic dominance of resistant *Pseudomonas aeruginosa*, Zipf's law is being used in its classically economic, or more accurately its 'capitalist', sense.

The original *Nature* paper (Zhao et al., 2013) presented in the editorial discussed immediately above does not go into very much detail on the original power laws upon which it is based. Instead it briefly mentions Zipf's law but also that of the Pareto principle: 'This Pareto-type behaviour indicates that the bacterial community self-organises in a manner analogous to a capitalist economic system' (ibid., 388). The principle, named after the right-wing Italian economist Vilfredo Pareto, is a distribution formula in which roughly eighty per cent of all effects (the possession of wealth say) are attributable to twenty per cent of the causes (ownership, entrepreneurship, etc.). In Zhao's article, both of

these power frameworks are derived from secondary summaries published in economics and physics (Gabaix 2009; Newman, 2005) rather than grappling with the cultural and political contingencies and contexts of their original sources.

Much of the above is evidence of the sustained and expanding influence of economic theory underpinning microbiology with calls for more explicit comparison between capitalist social systems and the behaviour of bacteria. Baranyi et al. (2015, p. 162) lament that ‘microbiology has not yet explored this idea sufficiently’ and argue for the compelling similarities of biology, ‘politics and industry’ (see also Gloag et al. 2015). Taking a more cognitivist position on biotic markets, another contribution to the debate calls for greater consideration of bacteria as ‘intensely social organisms’ exhibiting ‘... information pooling, control skew, speed vs. accuracy trade-offs, local feed backs, quorum thresholds, conflicts of interest... collective decision-making in microbes shares many features with collective decision-making in higher taxa...’ (Ross-Gillespie et al., 2015, p. 2; see also Cordero et al., 2012). There are frequent references in the scientific literature to wider commentary in financial services writing and the popular press. In just this vein Baranyi et al. (2015) support their argument with Cookson’s 2013a article in the *Financial Times* (entitled ‘How bacteria invest for success’). With somewhat startling poignancy in the post-2008 crash world, bacterial ecologies are understood to constantly vacillate between two countervailing responses to essentially economic crises: that of centrally imposed austerity on the one hand, and that of market driven consumption on the other (ibid.). Bacterial ecologies are seen to adapt to the anti-biotic environment by making adjustments to their ‘investment portfolio’ in resistant traits (Ross-Gillespie et al., 2015; see also Hibbing et al., 2010). Familiar debates in market economics figure prominently here, especially those pitching the relative merits of either competition and/or cooperation against one another. According to some the former are understood to overwhelmingly ‘dominate interactions between cultural microbial species’ (Foster and Bell, 2012; see also Nadell et al., 2016 and Freilich et al., 2011).

Maharjan et al. (2013), in their attempt to integrate experimental microbiology, synthetic biology and economic-mathematical modelling, propose a much more explicit comparison of bacterial and financial behaviour. They describe an economics of bacterial speculation (investment decisions) followed by ‘boom-bust’ cycles in response to certain antibacterial stressors (variable market conditions). ‘Successful’ bacterial strains are those able to balance the ‘trade-off’ between the evolution of stress-resistance (requiring the acquisition of costly proteins) or increasing consumption to grow. The study draws on nearly half a century of experimental biology on microbial ‘trade-offs’ but offers, what it describes as the ‘first experimental test of this theory based on a fully controlled trade-off between multiplication... and survival (resistance to external challenges)’ (ibid., 1268). In a media interview, one of the authors went on to argue that bacterial investment strategies ‘...are constrained by the subtleties in trade-offs that are usually invisible or ignored in real markets. The study is a classic demonstration of Darwinian economics and survival of the fittest’ (see the headline ‘Bacteria give lessons in investment economics’, BBC, 2013). The petri dish itself is seen to be a ‘living market’ in another *Financial Times* article entitled ‘Why bacteria are model investors’ (Cookson, 2013b). Building on this, a subsequent study distinguishes between what it calls ‘public’ and ‘private’ goods referring to the trade-off between shared or individually fixed assets, respectively (Bachmann et al., 2016; see also Ross-Gillespie et al., 2015). And another describes the ‘evolution of *fast and efficient* [our emphasis] anti-biotic bacterial genomes’ (Reding-Roman et al., 2017).

It should by now be clear that our point is to locate the expert microbiological construction of AMR in its cultural and political context. The discourses above can be understood as evidence of the naturalisation of economy rooted in the influence of multiple socio-economic registers. These include, but are not limited to sociobiology, classical market economics, functionalist sociology, cognitive neuroscience and even complexity theory. The references to Merton’s Matthew effect, Zipf’s law and the Pareto principle are only some of the many influences where theories of the market are interjected into the modelling of microbial ‘behaviour’ in AMR.

It is important therefore to think genealogically about the cross-currents of market imaginaries flowing between the social and biological sciences. In biology, power distribution formulae and genetic capitalism are proposed as neutral and objective descriptions of the selection pressures resulting in AMR. But in social science, concepts like that of the Matthew effect and even genetic capitalism are deployed as pejorative tools used to critique the modelling of the social on the biological. Both expressions enter discourse in order to challenge, in Merton’s case, the naturalisation of unequal distributions of reward. The term ‘genetic capitalism’ is first deployed in the mid 1970s by the anthropologist Marshall Sahlins in the battle of ideas against an ascendant sociobiology. For Sahlins (1976), genetic capitalism is intended to mock the naïve inscription of economic ideology first into nature, and then back to the social with all the obdurate force of nature behind it. What emerges is ‘...the entrenched ideology of Western society...’ (101) expressed succinctly as ‘genetic capitalism’ (72) legitimating the ‘naturalness’ and ‘inevitability’ of the ‘exploitation of others’ (77).

Genetic capitalism is therefore but another twist in the long-standing migration of economic theory into biology, and *visa versa*, dating to nineteenth century liberal political economy and beyond. The well trodden expression of this traffic in meaning goes back to Malthus, Spencer, the ‘survival of the fittest’, the migration of liberal economy into Darwinism, and its subsequent return in *laissez faire* economic market fundamentalism. Sahlins would possibly not be surprised to find a new variant of this here in what we call the ‘economisation of resistance’: ‘We seem unable to escape’ he writes, ‘...from this perpetual movement, back and forth between the culturalization of nature and the naturalisation of culture... It might be said that Darwinism, at first appropriated to society as ‘Social Darwinism,’ has returned to biology as a genetic capitalism...’ (ibid.).

It is therefore important to think about ‘genetic capitalism’ as an instance of the naturalisation of markets, or the re-appropriation of market economics into biology. Genetic capitalism is situated within a broader toing and froing across the hybridising boundaries of nature and culture. More recent articulations of genetic capitalism reflects critically on the material positioning of microbial life as agential in the production of capital, biowealth, and reproductivity of biovalue. This occurs both within and beyond the confines of antimicrobial resistance. Bardini (2011) writes of an economic turn towards the ‘invention of genetic capital’ whereby ‘junk’ DNA (surplus, excess, mutation, waste) is converted into ‘living money’ (see also Carruth 2011). Shukin (2009, p. 16) writes too of ‘animal capital’ and speculates on the contradictions of free market economic vulnerabilities to ‘novel diseases erupting out of the closed loop’ of a volatile bio-economic genome. Raley (2004) writes of the way postmodern theories of capitalism are articulated through the fusion of economic and biological conceptions of adaptation and mutation. For Braidotti (2013), late or advanced capitalism absorbs and is reproduced in the biological naturalisation of economy such that... ‘contemporary bio-genetic capitalism generates a global

form of reactive mutual inter-dependence of all living organisms, including non-humans' (49).

Concluding discussion

In this paper we have sought to outline two unfolding key registers in the cultural politics of antimicrobial resistance, both of which can be seen to constitute parallel economic framings of the problem of AMR. In 'economies of resistance' in biology, the operations of the market and principles of capitalist market-based political economy serve as the foundations for expert understandings of antibiotic resistance in experimental and observational microbiology. This trajectory can be seen to be reversed in the 'resistance of economies' outlined in the introduction above, whereby resistant infections become a vehicle for a somewhat right-of-centre politics of welfare state reform, privatisation, the securitisation of national borders and reinvigoration of pharmaceutical commercial enterprise. Whilst this is a modest step in better understanding underlying economic and cultural framings, more critical reflection and empirical enquiry needs to be directed at the mutual co-production of the science and politics of AMR. How is it, and through what chains of agency, authorship, endeavour and translation, that the science and politics of anti-biosis supply meaning to one another? Such a question goes way beyond the ambitions of this paper and instead points to a far wider critical research agenda within the medical humanities and social sciences.

We would however argue for a sustained focus on the immunary biopolitics of the anti-biosis, and the way in which the 'problem' of AMR expresses deeply hybrid entanglements of economy and biology. We can see this in, for instance, the twentieth century shift from a static self-versus-non-self paradigm of immunity, to one focussed on a dynamic traffic of exchange in immunary properties. Economies of resistance centre on the ascendancy of globally mobile epidemic strains of resistant bacterial species, resulting from accelerated processes of gene swapping, acquisition and random variation. It is in this way that a rigidly self-other framework subsequently gives way to a revised model and understanding of the immune system anchored in the flexibly dynamic and responsive features of post-fordist and subsequently neoliberal capitalism. Immune system discourse and knowledge becomes preoccupied with porosity, flecked with idioms derived from 'networked' economic enterprise, computational neuroscience, and the logics of flexible accumulation and just-in-time production.

Just as AMR is beginning to take shape as a problem for policy and politics, roughly from around the 1980s and into the 1990s, immunity begins to mirror the attributes and features of a decentralised form of capitalism characterised by geographical and temporal flexibility responding dynamically to global fluctuations in the costs of labour, exchange rate variations and market volatility. Immunity, infectivity and defence mimic these major shifts in the workings of markets, the workplace itself, the organisation of labour and the underlying market principles of state institutions. It is this synergy between immunity and the logics of flexible specialisation that allows advanced capitalism to become resident in the very corporeal fabric of our co-evolution with microbial life. It is possibly in these terms, and in a very different context that Helmreich writes of the way evolutionary capitalism increasingly 'structures the actual threats to which networks are subject, resistance to national and market forces may indeed begin to speak in the language assigned it by the dominant discourse' (2000, p. 485).

It is in the work of Emily Martin that this sense of an economic imaginary has been most explicitly expressed in her claim that that '... the immune system has risen to eminence in Euro-

American culture...' (1994, p. 32). For Martin, immunity is inextricably linked to the political and moral economics of business, security, class, racism and gender. Twentieth century scientific immunological discourse is littered with language that codifies working class bodies as immunologically unfit and auto-destructive. Immune systems are racially configured in fighting off invading 'foreign' hoards, and gendered through notions of passivity and aggression. Immunity has also become a means of comparative socio-economic striation and segmentation. Martin documents the changing historical articulations of capital through both expert-biomedical and popular representations of immunity. Here immunity operates to mutually define and then redefine the entanglement of politics, economy and biology. Her account charts the transition from an early and mid-twentieth century account of immunity as the basis for the protected prosperity and the security of the nation state, to that of a globally flexible, dynamic and transnational capitalist fluid order. For Martin then, we have two parallel versions of immunity. One is anchored in the bounded and hermetically sealed notion of the defensive militaristic nation rooted in the economic competition of cold war imperial rival powers. The second is modelled on the post-empire fragmented flexible dynamism of late capitalism. Immunity here expresses multiple contending versions of economic organisation and their competing claims to 'naturalness'. Martin's take on the immunity-economy nexus, we suggest, is essential to understanding concepts like that of genetic capitalism and economic imaginaries in the biology of AMR.

Forms of economy and the economic imaginary figure too in the way the immune system underpins technological security and particularly the vulnerability of computational systems to the spread of contagious infection. Helmreich (2000) focuses on computer security rhetoric and the way notions of capital and capitalism 'powerfully shape the way computer viruses are construed and combated' (p. 472). Popular understandings of infectivity and contagion re-encode computational code through biological notions of immunology. Ultimately, such immunological frameworks are underpinned by an evolutionary discourse that rests on economic conceptions of flexibly adaptive economy, yet another variation on what Helmreich himself calls 'evolutionary capitalism'.

Evolutionary capitalism clearly echoes and chimes with biological research literature in which capitalism is similarly seen to provide a naturalised template for the biology of antimicrobial resistance. But in Helmreich's hands, computational security depends upon defensive protocols, algorithms that incorporate, in their design, the 'virtues' of flexible adaptability, values 'connected to market ideals of advanced capitalism production and also to contemporary descriptions of the immune system' (p. 473). Neo-evolutionary theory therefore provides a means with which to conceive of the capacity of computational code to capitalise on adaptability in order to 'out-evolve' new viruses, or other bacterial organisms in the context of AMR. In this way, the simile of immunity and neo-evolutionism becomes physically embedded in material processes (code, algorithms, defences) that, in turn, endorse the economic and evolutionary foundations upon which they are based. In contexts like this, we suggest, there is a mutually reinforcing circuitry between immunity, economy and code. Helmreich writes that the '... solution to the problem of giving immunity [code] to viruses, solved initially in terms of the biological metaphor, is played out on the field of flexibly specific capitalist production, from where it can double back to confirm the validity of the biological metaphor...' (486). This provides yet another way for thinking about how microbial threats become interwoven into the dominant language of capitalistic market forces such that computer viruses, in this case, are seen to

appropriate the very evolutionary adaptive virtues that they are seen also to attack.

It is then of little surprise that much of the language and conceptual terrain of immunity, predates its coinage in biomedical discourse, and instead originates in economic and political organisation. Both Cohen and Esposito have traced the etymological and genealogical roots of immunity in political and moral economic order. For Esposito (2008), immunity is traceable to the classical Roman principle of the *munus*, the obligatory bond of dutiful and sometimes burdensome citizenship. Cohen focuses on the way immunity underpins an early modern politics of individualism, autonomy, exemption and self-possession. He then turns to the way immunitary individualism becomes encoded in biological and scientific understanding. Indeed, such is the profound success of this process of naturalisation that we no longer remember or think of immunity as first and foremost biopolitical or socio-economic. 'Biomedicine' he argues 'fuses' and 'then transplants this new biopolitical hybrid into the living human body. We have not been the same since' (Cohen, 2009, p. 3). Jamieson (2016) has been critical of the uni-direction of travel evident in Cohen's work, and possibly that of others, whereby juridical and constitutional notions of immunity prefigure a biological meaning that 'comes after' that of the political. Nevertheless, she recognises how the politics and economy of immunity articulate the way, as she puts it '... situated world views or dominant cultural values, permeate the world of scientific facts... facts so often taken as axiomatic are themselves evidence of our collective investment in certain political and social ideas' (ibid., 3). Again, in the context of our discussion here, we do not assign any particular primacy to either economic-political or medico-scientific registers of resistance to antimicrobials. Rather, we are interested in the alternating expressions of economic imaginaries as they move between politics and biology.

There are other cultural agendas to be alert to here as well. It is probably important to think more critically about subtle shifts in the political emphasis on AMR. How is it that biological understanding, political practice and policy-making serve to reinforce one another, often unwittingly, in notions of surveillance and exposure that reinforce naturalised discourses of sovereignty (the individual, the nation, bacterial investors, etc.). There is more to be said of course about aspects of monitoring and surveillance preoccupied with the role of international travel, and the vulnerabilities of the traveller, in AMR. Interestingly, this question was also addressed more recently by one of the microbiology sources for 'economies of resistance' discussed above (see Zhou et al., 2014). There is also more to understand in the way the politics of AMR, only relatively recently in the post-austerity period, moved on from a concern with labour relations, privatisation and welfare reform. Instead, in the midst of the Brexit years, there is much to unravel about an anti-biosis politics underpinned by questions of surveillance, vigilance, sanitation and a renewed commitment to the integrity of borders. Our undertaking here is but a small attempt to understand just some of the threads proliferating in the cross currents between the biology and politics of AMR, between 'economies of resistance' and the 'resistance of economies'.

Received: 4 May 2018 Accepted: 28 September 2018

Published online: 23 October 2018

References

Bachmann H, Bruggeman FJ, Molenaar D, dos Santos FB, Teusink B (2016) Public goods and metabolic strategies. *Curr Opin Microbiol* 31:109–115

- Baquero F (2004) From pieces to patterns: evolutionary engineering in bacterial pathogens. *Nat Rev Microbiol* 2(6):510
- Baquero F, Coque TM, Canton R (2003) Antibiotics, complexity, and evolution-perspective-antibiotic usage increases disorder at different biological levels, promoting the emergence of alternative orders in the microbiosphere. *ASM News-Am Soc Microbiol* 69(11):547–552
- Baranyi J, Metris A, George SM (2015) Bacterial economics: adaptation to stress conditions via stage-wise changes in the response mechanism. *Food Microbiol* 45:162–166
- Bardini T (2011) *Junkware*. University of Minnesota Press, Minneapolis
- BBC (2013) Bacteria give lessons in investment economics. <https://www.bbc.co.uk/news/science-environment-23623601> Accessed 1st June 2018
- Beck S (2011) Staging bone marrow donation as a ballot: reconfiguring the social and the political using biomedicine in cyprus. *Body Soc* 17(2-3):93–119
- Braidotti R (2013) *The Posthuman*. Polity Press, Cambridge
- Brown N (2018) *Immunitary Life: a biopolitics of immunity*. Palgrave Macmillan, London
- Brown N, Nettleton S (2017) There is worse to come: The biopolitics of traumatism in Antimicrobial Resistance (AMR). *Sociol Rev* 65(3):493–508
- Brown N, Machin L, McLeod D (2011) Immunitary bioeconomy: the economisation of life in the international cord blood market. *Social Sci Med* 72(7):1115–1122
- Brown N, Williams R (2015) Cord blood banking—bio-objects on the borderlands between community and immunity. *Life Sci Soc Policy* 11(1):1–18
- Carruth A (2011) Junk culture and the post-genomic age. *Postmod Cult* 21:2
- Chandler C, Hutchinson E, Hutchison C (2016) Addressing antimicrobial resistance through social theory: an anthropologically oriented report. London School of Hygiene and Tropical Medicine. <http://www.lshtm.ac.uk/php/ghd/research/app/anthropologyofantimicrobialresistance.html>. Accessed June 2018
- Cohen E (2009) *A body worth defending: Immunity, biopolitics, and the apotheosis of the modern body*. Duke University Press, Durham
- Cookson C (2013a, August 16) How bacteria invest for success, *Financial Times Magazine*
- Cookson C (2013b, August 16) Why bacteria are model investors, *Financial Times Magazine*
- Cooper M (2006) Pre-empting emergence: the biological turn in the war on terror. *Theory Cult Soc* 23(4):113–135
- Cordero OX, Wildschutte H, Kirkup B, Proehl S, Ngo L, Hussain F, Polz MF (2012) Ecological populations of bacteria act as socially cohesive units of antibiotic production and resistance. *Science* 337(6099):1228–1231
- Craig GM (2007) 'Nation', 'migration' and tuberculosis. *Social Theory Health* 5(3):267–284
- Crawford P, Brown B, Nerlich B, Koteyko N (2008) 'The "moral careers" of microbes and the rise of the matrons: an analysis of UK national press coverage of methicillin-resistant *Staphylococcus aureus* (MRSA) 1995–2006'. *Health Risk Soc* 10(4):331–347
- Department of Health (2000) UK Antimicrobial Resistance Strategy and Action Plan. Department of Health. June http://webarchive.nationalarchives.gov.uk/20130107105354/http://www.dh.gov.uk/prod_consum_dh/groups/dh_digitalassets/@dh/@en/documents/digitalasset/dh_4078448.pdf Accessed Oct 2017
- Esposito R (2008) *The philosophy of bios. Bios: biopolitics and philosophy*. trans. Timothy Campbell. University of Minnesota Press, Minneapolis, London
- Foster KR, Bell T (2012) Competition, not cooperation, dominates interactions among culturable microbial species. *Curr Biol* 22(19):1845–1850
- Foucault M (1991) Questions of method. In: Burchell G, Gordon C, Miller P(eds) *The Foucault effect: studies in governmentality..* Harvester Wheatsheaf, Hertfordshire
- Freilich S, Zarecki R, Eilam O, Segal ES, Henry CS, Kupiec M, Ruppin E (2011) Competitive and cooperative metabolic interactions in bacterial communities. *Nat Commun* 2:589
- Gabaix X (2009) Power laws in economics and finance. *Annu Rev Econ* 1(1):255–294
- Gloag ES, Turnbull L, Whitchurch CB (2015) Bacterial stigmery: an organising principle of multicellular collective behaviours of bacteria. *Scientifica* 1–8
- Haraway D (1999) The biopolitics of postmodern bodies: determinations of self in immune system discourse. In: Price J, Shildrick M (eds) *Feminist theory and the body: a reader*. Edinburgh University Press, Edinburgh, p 203–214
- Helmreich S (2000) Flexible infections: computer viruses, human bodies, nation-states, evolutionary capitalism. *Sci Technol Human Values* 25(4):472–491
- Hibbing ME, Fuqua C, Parsek MR, Peterson SB (2010) Bacterial competition: surviving and thriving in the microbial jungle. *Nat Rev Microbiol* 8(1):15
- Jamieson M (2016) The politics of immunity: reading Cohen through Canguilhem and New materialism. *Body Soc* 22(4):106–129
- Jasanoff S (2004) The idiom of co-production. In: Jasanoff S (Ed.) *States of knowledge: the co-production of science and social order*. Routledge, New York, p 1–12

- Jessop B (2004) Critical semiotic analysis and cultural political economy. *Crit Discourse Stud* 1(2):159–174
- Jessop B, Oosterlynck S (2008) Cultural political economy: on making the cultural turn without falling into soft economic sociology. *Geoforum* 39(3):1155–1169
- Juan C, Zamorano L, Mena A, Albertí S, Pérez JL, Oliver A (2010) Metallo- β -lactamase-producing *Pseudomonas putida* as a reservoir of multidrug resistance elements that can be transferred to successful *Pseudomonas aeruginosa* clones. *J Antimicrob Chemother* 65(3):474–478
- Landecker H (2016) Antibiotic resistance and the biology of history. *Body Soc* 22(4):19–52
- Leavis HL, Bonten MJ, Willems RJ (2006) Identification of high-risk enterococcal clonal complexes: global dispersion and antibiotic resistance. *Curr Opin Microbiol* 9(5):454–460
- Li G, Brown PJ, Tang JX, Xu J, Quardokus EM, Fuqua C, Brun YV (2012) Surface contact stimulates the just-in-time deployment of bacterial adhesins. *Mol Microbiol* 83(1):41–51
- Maharjan R, Nilsson S, Sung J, Haynes K, Beardmore RE, Hurst LD, Gudelj I (2013) The form of a trade-off determines the response to competition. *Ecol Lett* 16(10):1267–1276
- Martin E (1994) Flexible bodies: tracking immunity in American culture from the days of polio to the age of AIDS. Beacon Press, Chicago
- Martin E (1997) Designing flexibility: science and work in an age of flexible accumulation. *Sci Cult* 6(3):327–362
- Merton RK (1968) The Matthew effect in science: the reward and communication systems of science are considered. *Science* 159(3810):56–63
- Nadell CD, Drescher K, Foster KR (2016) Spatial structure, cooperation and competition in biofilms. *Nat Rev Microbiol* 14(9):589
- Nerlich B, James R (2009) “The post-antibiotic apocalypse” and the “war on superbugs”: catastrophe discourse in microbiology, its rhetorical form and political function. *Public Underst Sci* 18(5):574–590
- Nettleton S, Woods B, Burrows R, Kerr A (2009) Food allergy and food intolerance: towards a sociological agenda. *Health* 13(6):647–664
- Newman MEJ (2005) Power laws, Pareto distributions and Zipf’s law. *Contemp Phys* 46:323–351
- Raley R (2004) eEmpires. *Cult Crit* 57(1):111–150
- Reding-Roman C, Hewlett M, Duxbury S, Gori F, Gudelj I, Beardmore R (2017) The unconstrained evolution of fast and efficient antibiotic-resistant bacterial genomes. *Nat Ecol Evol* 1(3):0050
- Römling U (2013) Microbiology: bacterial communities as capitalist economies. *Nature* 497(7449):321
- Ross-Gillespie A, Dumas Z, Kümmerli R (2015) Evolutionary dynamics of inter-linked public goods traits: an experimental study of siderophore production in *Pseudomonas aeruginosa*. *J Evol Biol* 28(1):29–39
- Sahlins MD (1976) The use and abuse of biology: an anthropological critique of sociobiology. University of Michigan Press, Ann Arbor
- Shukin N (2009) Animal capital: Rendering life in biopolitical times. University of Minnesota Press, Minneapolis
- Tauber AI (1998) Conceptual shifts in immunology: comments on the ‘two-way paradigm’. *Theor Med Bioeth* 19(5):457–473
- Waldby C, Mitchell R (2006) Tissue economies: blood, organs, and cell lines in late capitalism. Duke University Press, London
- Willems RJ, Top J, Marga van Santen D, Coque TM, Baquero F, Grundmann H, Bonten MJ (2005) Global spread of vancomycin-resistant *Enterococcus faecium* from distinct nosocomial genetic complex. *Emerg Infect Dis* 11(6):821
- Wring D (2005) The labour campaign. *Parliam Aff* 58(4):712–724
- Zhou YP, Wilder-Smith A, Hsu LY (2014) The role of international travel in the spread of methicillin-resistant *Staphylococcus aureus*. *J Travel Med* 21(4):272–281
- Zhao K, Tseng BS, Beckerman B, Jin F, Gibiansky ML, Harrison JJ, Wong GC (2013) Psl trails guide exploration and microcolony formation in *Pseudomonas aeruginosa* biofilms. *Nature* 497(7449):388

Data availability

Data sharing is not applicable as no datasets were analysed or generated.

Additional information

Competing interests: The authors declare no competing interests.

Reprints and permission information is available online at <http://www.nature.com/reprints>

Publisher’s note: Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.



Open Access This article is licensed under a Creative Commons Attribution 4.0 International License, which permits use, sharing, adaptation, distribution and reproduction in any medium or format, as long as you give appropriate credit to the original author(s) and the source, provide a link to the Creative Commons license, and indicate if changes were made. The images or other third party material in this article are included in the article’s Creative Commons license, unless indicated otherwise in a credit line to the material. If material is not included in the article’s Creative Commons license and your intended use is not permitted by statutory regulation or exceeds the permitted use, you will need to obtain permission directly from the copyright holder. To view a copy of this license, visit <http://creativecommons.org/licenses/by/4.0/>.

© The Author(s) 2018