A Multi-Sectoral Agent-Based Monetary Model

of Transition to a Low-Carbon Economy

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Introduction

Two of the greatest challenges of our age are the tasks of transitioning to low-carbon economies in order to mitigate climate change, and of restoring financial balance and stability. The resulting more stable, low-carbon economies must in turn deliver sustainable and equitable livelihoods.

The 'Great Crash' of 2008 laid bare the limitations of much modern macroeconomic theory and analysis (Kirman 2010, Ormerod 2010, Keen 2011, Wray 2011). Even the former Chairman of the US Federal Reserve, Alan Greenspan, remarked:

> Those of us who have looked to the self-interest of lending institutions to protect shareholders' equity, myself included, are in a state of shocked disbelief. … This modern risk-management paradigm held sway for decades. The whole intellectual edifice, however, collapsed in the summer of last year (Andrews, 2008).

In reference to the Great Crash, it is often asserted that 'no-one saw it coming'. But as Bezemer (2009, 2011) showed, this is simply untrue. Several economists did in fact predict not only the impending 'reality check' of the Great Crash, but just as importantly, its timing and its origins. A common feature of their analysis was the use of flow-of-funds models which keep track of debt levels, firm balance sheets and financial *dis*equilibria, rather than assuming a neoclassical equilibrium framework (see e.g. Keen 2011a,b, Godley & Lavoie, 2007). The work of Hyman Minsky (1982, 1986) also features prominently in their analysis – for example Keen (2011a) and Wray (2012).

As noted by Beale *et al.* (2011), a system-wide perspective is also essential, since actions that may reduce risk for individual firms in isolation may, and indeed did, make the financial system as a whole far more fragile. While regulators tried to keep up with rapid innovations at the firm level, very few were absorbing the implications of these firm-level activities for the system as a whole.

Meanwhile, the limitations of neoclassical economic models of climate change and integrated assessment models (IEMs) have been extensively documented (e.g. DeCanio 2003, Ackerman 2008, Ackerman *et al.* 2009, Ackerman & Stanton 2011). One of the key limitations with such models is the omission of financial realities such as firm balance sheets, debt levels, credit and equity markets, insurance premia and so on. These omissions are critical for two reasons: Firstly because the economic impacts of climate change may be vastly underestimated by omitting financial market effects (Michael 2007). And secondly, because it is not simply the end state of a low-carbon economy that must be depicted. Just as important is the viability of the transition path that shows that getting there is feasible. It is no longer adequate, if it ever was, to adopt the traditional comparative statics approach of much economic analysis, in which 'before' and 'after' snapshots of an economy in equilibrium are taken and a viable transition path between them is simply assumed.

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One of the most influential IEMs has been Nordhaus's Dynamic Integrated model of Climate and the Economy (DICE) model (see e.g. Nordhaus 2007a,b and 2008). Nordhaus has used this model to argue against the need for urgent action on climate change, claiming that the *Stern Review* (Stern 2007) reached novel conclusions by giving too great a weight to the future (in technical terms, using too low a discount rate), which did not reflect actual discount rates reflected in market interest rates. To say that Nordhaus's approach causes consternation among those who think that the future in 100 years should be valued at greater than nothing, is something of an understatement, as DeCanio (2003) and Ackerman *et al.* (2009) attest.

Australia's Garnaut Review (Garnaut 2008, 2011) used a more sophisticated modelling approach, linking models of different species, but again, this state-of-the-art effort was hampered by the lack of availability of integrated monetary and biophysical models that could adequately reflect the impacts of climate change on the economy and society. These impacts include not only its direct physical impacts such as drought, bushfires and sea-level rise, but also the reverberations through the economic and financial systems of those impacts and of efforts to adapt to and mitigate climate change.

New models are needed that integrate the real, financial, social and biophysical dimensions of economies so that they can more realistically model the transition paths needed to ensure a more sustainable future. This extended abstract reports on work in progress towards such a model.

The Model

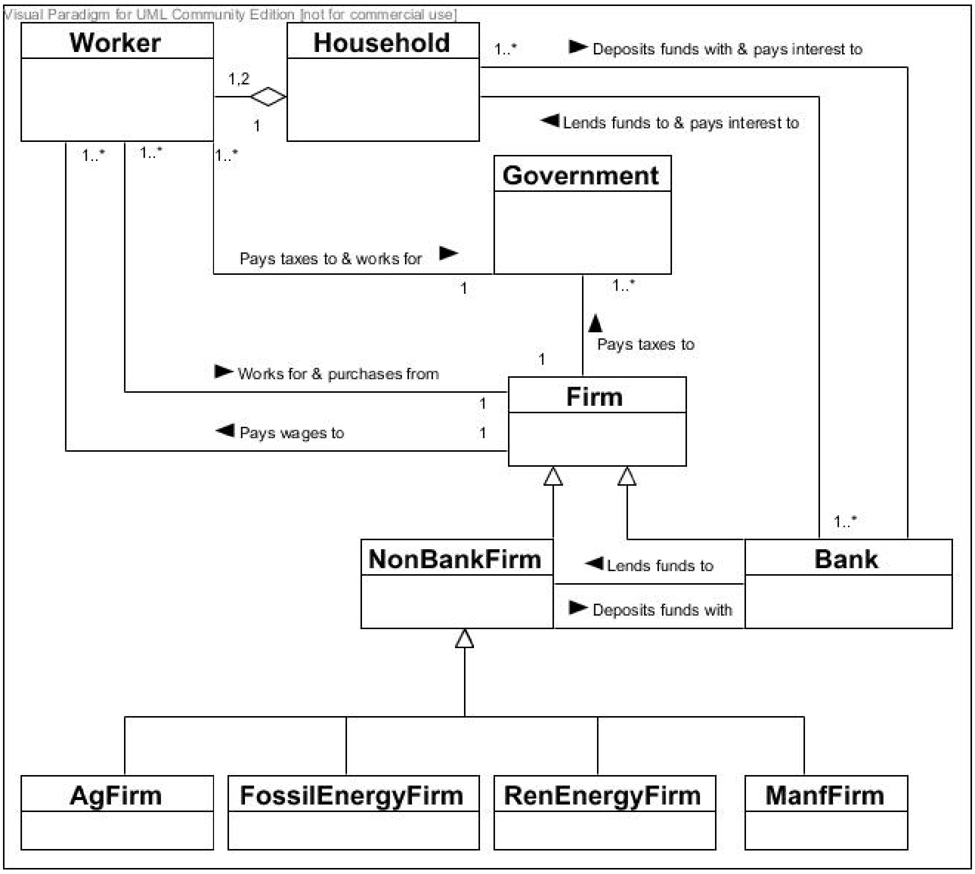
The model builds on several recent contributions, including Dosi et al. (2008, 2010), Godley and Lavoie (2007 and 2012), and Keen (2010, 2011a and 2012). The model is implemented in NetLogo (Wilensky 1999).

The question of scale and the inter-relationships between different levels of the system is critical (Ahl & Allen 1996; Manson 2008). Some agent-based models have millions of agents, with a separate agent for every individual. ABMs inevitably face a trade-off between numbers of agents and their interactions, and the computational burden and speed of execution. Our aim in this model is to represent and integrate key elements of the system, more as a proof of concept, rather than seeking detailed, calibrated fidelity at the level of individual people and firms. The actions of individual people, households and firms are nevertheless important for the evolution of economic systems. We have therefore adopted the approach of using 'super-individuals' (Scheffer *et al*. 1995) where individual people, households and firms have relationships and act in ways appropriate to individuals, but the amounts they consume, produce, borrow and so on are far greater than 'normal' individuals. In this way an individual may represent many hundreds of individuals. Similar questions pertain to the spatial and temporal resolutions – finer-grained representations permit greater fidelity to real-world processes, but again, dramatically increase the computational burden and complexity of the model. At the time of writing this abstract we are still determining the precise numbers and resolutions necessary to give the best mix for our purposes. It is not possible to describe the model in detail in a short abstract, but Figure 1 gives an indication of the principle classes and flows of funds.

Workers (*W*) are members of *Households (HH)*, which include children (CH, not shown) who must be nourished and educated in order to become productive workers. *Workers* work for *Firms (F)* and Government (*G*) and receive wages (*w*) for their labour (*L*). *Households* must pay taxes to the *Government* and must purchase the products of the different kinds of *Firms* to survive.

There are two primary types of *Firms*: *Banks* (B) and *NonBankFirms* (NBF). *NonBankFirms* are further subdivided into four main industry sectors: agricultural firms (*AgFirms, AF*), manufacturing firms (*ManfFirms, MF*) and two kinds of *EnergyFirms* (*EF*) – fossil energy firms (*FossilEnergyFirms, FEF*) which are greenhouse gas emissions-intensive and renewable energy firms (*RenEnergyFirms, REF*) which are far less emissions-intensive. Energy is critical, not simply because the focus here is on the transition to a low-carbon economy, but because too often energy is not given its due weight in considerations of the crucial drivers of economic growth (Frondel & Schmidt, 2004).

Figure 1. Class diagram of the main features and flows in the model



All four types of *NonBankFirms* require finance from banks. *AgFirms* require inputs from *EnergyFirms* and *ManfFirms* as well as arable land and water (not shown in Figure 1); *EnergyFirms* require inputs from *ManfFirms* and *EnergyFirms*; and *ManfFirms* require inputs from *EnergyFirms* and *ManfFirms*. *Households* require inputs from energy, agriculture (food) and manufacturing. Inputs are purchased with money or credit flowing between the relevant accounts and prices are absolute rather than relative price ratios.

The *NonBankFirms* rely on the *Banks* for credit and must pay the banks interest on borrowed funds. *Firms* pay taxes to the *Government* and also issue equity (*e*, not shown). *Firms* must also innovate to improve their energy efficiency and product offerings in order to survive. Following Schumpeter (1934), the extension of credit to firms is an essential ingredient in the process of innovation, which in turn is arguably the major driver of economic development.

The *Government* receives taxes (*t*) from *Workers* and *Firms* and must spend a certain proportion of funds on health (HL), education (ED), social security (SOS) and infrastructure (INF) to maintain a productive economy and stable society. The *Government* must also survive an 'election' every three to four years, based on its popularity with *Workers*. If the Government loses the election, an alternative set of policies is introduced. The two sets of policies available to the Government agent are based on policies reflective of 'Conservative/Republican' and 'Democrat/Labour/Green' parties in the Western democracies. This aspect of the model can be developed to incorporate an important spatial aspect of the transition, namely the fact that certain geographical areas are affected more than others, particularly those in which fossil-fuel intensive industries are concentrated, or those which stand to gain from the transition through, for example, investment in renewable energy industries.

In common with most ABMs, the model contains considerable stochasticity, particularly in the ways in which agents are interact. Random numbers are used in a variety of ways in the construction of the agents and in their interactions as the system evolves. Since all computer-generated random numbers are deterministic however, these are strictly speaking only 'pseudo-random' numbers rather than true random numbers. Model runs can be replicated precisely by setting and using the same random 'seed' number for the random number generator. We use this feature by incrementally increasing the random seed for multiple model runs to ensure that the results are not an artefact of a particular random seed.

The key challenge for the *Government*, *Households* and *Firms* is to manage the transition from a fossil-fuel intensive economy to a low-carbon economy. Substantial emissions reductions must be undertaken between 2010 and 2050, in accordance with the recommendations of the Intergovernmental Panel on Climate Change (IPCC, 2007). This implies that energy production and use in the economy must become far less emissions-intensive. This in turn implies that appropriate policies must be put in place to encourage such a transition without causing financial instability, credit crunches or unnecessary bankruptcies of otherwise viable firms. Since these policies must also be voted into place in democratic countries, low unemployment, financial stability and social cohesion is vital to the transition.

The ABM incorporates likely long-term impacts of climate change such as lower agricultural productivity and rising sea-levels, as well as discrete disaster events such as cyclones, bushfires and heatwaves. These different types of climate impacts are treated distinctly rather than lumping them together in the form of a 'damage curve' as is common with many IEMs.

Conclusion

This model is part of a wider research program intended to help provide a bridge between some of the most insightful analyses of modern monetary economics and financial instability, and the integrated assessment literature modelling potential transition paths to low-carbon economies. An agent-based modelling framework is ideally suited to such a task by providing a dynamic, spatial environment in which large numbers of heterogeneous agents can interact and evolve.

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References

Ackerman, F., (2008) *Can We Afford the Future? The Economics of a Warming World,* The New Economics Series; Zed Books, London & New York, viii +151 pp.

Ackerman, F., DeCanio, S.J., Howarth, R.B. and Sheeran, K., (2009) "Limitations of Integrated Assessment Models of Climate Change", *Climatic Change,* Vol. 95, No. 3-4, August, pp. 297-315.

Ackerman, F. and Stanton, E.A., (2011) *Climate Economics: The State of the Art*, Stockholm & Somerville MA, Stockholm Environment Institute, November, 148 pp. http://sei-us.org/publications/id/417

Ahl, V. and Allen, T.F.H., (1996) *Hierarchy Theory: A Vision, Vocabulary, and Epistemology,* Colombia University Press, New York, 206 pp.

Andrews, E.L., (2008) "Greenspan Concedes Error in Regulation", *New York Times,* 23 October, p. B1. http://www.nytimes.com/2008/10/24/business/economy/24panel.html

Beale, N., Rand, D.G., Battey, H., Croxson, K., May, R.M. and Nowak, M.A., (2011) "Individual versus Systemic Risk and the Regulator's Dilemma", *Proceedings of the National Academy of Sciences,* Vol. 108, No. 31, 2 August, pp. 12647-12652. http://www.pnas.org/content/108/31/12647.abstract

Bezemer, D.J., (2009) "“No One Saw This Coming”: Understanding Financial Crisis Through Accounting Models", Munich University, Munich Personal RePEc Archive, MPRA Paper No. 15892, 16 June, 50 pp. http://mpra.ub.uni-muenchen.de/15892/

Bezemer, D.J., (2011) "The Credit Crisis and Recession as a Paradigm Test", *Journal of Economic Issues,* Vol. 45, No. 1, March, pp. 1-18.

DeCanio, S.J., (2003) *Economic Models of Climate Change: A Critique*, Palgrave Macmillan, New York & Houndmills, Basingstoke, UK, xiii + 203 pp.

Dosi, G., Fagiolo, G. and Roventini, A., (2008) "The Microfoundations of Business Cycles: An Evolutionary, Multi-Agent Model", *Journal of Evolutionary Economics*, Vol. 18, No. 3, August, pp. 413-432.

Dosi, G., Fagiolo, G. and Roventini, A., (2010) "Schumpeter Meeting Keynes: A Policy-Friendly Model of Endogenous Growth and Business Cycles", *Journal of Economic Dynamics and Control,* Vol. 34, No. 9, September, pp. 1748-1767.

Frondel, M. and Schmidt, C.M., (2004) "Facing the Truth about Separability: Nothing Works without Energy", *Ecological Economics,* Vol. 51, No. 3-4, December, pp. 217-223.

Garnaut, R., (2008) *The Garnaut Climate Change Review: Final Report,* Cambridge University Press, Melbourne, xlv + 616 pp.

Garnaut, R., (2011) *The Garnaut Review 2011: Australia in the Global Response to Climate Change,* Cambridge University Press, Cambridge, Melbourne & New York, xx + 221 pp.

Godley, W. and Lavoie, M., (2007) "Fiscal Policy in a Stock-Flow Consistent (SFC) Model", *Journal of Post Keynesian Economics,* Vol. 30, No. 1, Fall, pp. 79-100.

Godley, W. and Lavoie, M., (2012) *Monetary Economics: An Integrated Approach to Credit, Money, Income, Production and Wealth,* 2nd Edition; Palgave Macmillan, Houndmills, Basingstoke & New York, xlvi+ 530 pp.

IPCC, (2007) *Climate Change 2007: Mitigation. Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*, ed. Metz, B., Davidson, O.R., Bosch, P.R., Dave, R. and Meyer, L.A.; Cambridge University Press, Cambridge & New York, pp. viii + 851.

Keen, S., (2010) "Solving the Paradox of Monetary Profits", *Economics: The Open-Access, Open-Assessment E-Journal,* Vol. 4, No. 2010-31, 28 October, pp. 1-32. http://www.economics-ejournal.org/economics/journalarticles/2010-31

Keen, S., (2011a) "A Monetary Minsky Model of the Great Moderation and the Great Recession", *Journal of Economic Behavior & Organization,* In press, Corrected proof, Online 1 February pp. 1-15.

Keen, S., (2011b) *Debunking Economics - Revised and Expanded Edition: The Naked Emperor Dethroned?,* Zed Books, London & New York, xviii + 478 pp.

Keen, S., (2012) "A Dynamic Monetary Multi-sectoral Model of Production", Unpublished manuscript, University of Western Sydney, 1-29 pp. http://www.debtdeflation.com/blogs

Kirman, A., (2010) "The Economic Crisis is a Crisis for Economic Theory", *CESifo Economic Studies,* Vol. 56, No. 4, December, pp. 498-535. http://cesifo.oxfordjournals.org/content/56/4/498.abstract

Manson, S.M., (2008) "Does Scale Exist? An Epistemological Scale Continuum for Complex Human-Environment Systems", *Geoforum,* Vol. 39, No. 2, March, pp. 776-788.

Michael, J.A., (2007) "Episodic Flooding and the Cost of Sea-level Rise", *Ecological Economics,* Vol. 63, No. 1, 15 June, pp. 149-159.

Minsky, H.P., (1982) *Can "It" Happen Again? Essays on Instability and Finance,* M.E. Sharpe, Armonk NY & London, xxiv + 301 pp.

Minsky, H.P., (1986) *Stabilizing an Unstable Economy,* McGraw Hill, New York, 2008 Edition, xxxv + 395 pp.

Nordhaus, W.D., (2007a) "A Review of the Stern Review on the Economics of Climate Change", *Journal of Economic Literature,* Vol. 45, No. 3, September, pp. 686-702.

Nordhaus, W.D., (2007b) "Critical Assumptions in the Stern Review on Climate Change", *Science,* Vol. 317, No. 5835, 13 July, pp. 201-202.

Nordhaus, W.D., (2008) *A Question of Balance: Weighing the Options on Global Warming Policies,* Yale University Press, Boston MA, 256 pp.

Ormerod, P., (2010) "The Current Crisis and the Culpability of Macroeconomic Theory", *Twenty-First Century Society,* Vol. 5, No. 1, February, pp. 5-18. http://www.paulormerod.com/pdf/accsoct09%20br.pdf

Scheffer, M., Baveco, J.M., DeAngelis, D.L., Rose, K.A. and van Nes, E.H., (1995) "Super-Individuals: A Simple Solution for Modelling Large Populations on an Individual Basis", *Ecological Modelling,* Vol. 80, No. 2-3, July, pp. 161-170.

Schumpeter, J.A., (1934) *The Theory of Economic Development: An Enquiry into Profits, Capital, Credit, Interest and the Business Cycle,* Transaction Publishers reprint, 1983, New Brunswick NJ & London; trans. from the 2nd German edition of 1926 by Redvers Opie, lxiv + 255 pp.

Wilensky, U., (1999) "NetLogo", http://ccl.northwestern.edu/netlogo/, Evanston, IL, Center for Connected Learning and Computer-Based Modeling, Northwestern University.

Wray, L.R., (2011) "The Dismal State of Macroeconomics and the Opportunity for a New Beginning", Working Paper No. 652, Annandale-on-Hudson, NY, Levy Economics Institute of Bard College, March, 22 pp. http://www.levyinstitute.org/pubs/wp_652.pdf

Wray, L.R., (2012) "Global Financial Crisis: A Minskyan Interpretation of the Causes, the Fed's Bailout, and the Future", Working Paper No. 711, Annandale-on-Hudson, NY, Levy Economics Institute of Bard College, March, 30 pp. http://www.levyinstitute.org/pubs/wp_711.pdf