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Modelling evolving patterns of land-use: the FEARLUS model

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[EDITED TRANSCRIPT]

OK, my name's Gary Polhill and I'm based at the Macaulay Land Use Research Institute in Aberdeen. Thank you very much for inviting me here Paul to talk to you about modelling involving patterns of land use and Paul asked me to focus on work in the FEARLUS Model, I should say right from the outset that other models of agent based models of land use are available. Quite a lot of people to acknowledge, I mean I should I suppose firstly say that pretty much most, all of this work has been done in collaboration with Nick Gotts at the Macaulay Land Use Research Institute as well, so that's why I've sort of put him as co-author on this presentation, though it's mostly my responsibility this particular presentation.

So over the time there have been various collaborators, Alistair Law, Luis Izquierdo, Lee-Ann Sutherland, Pernette Belveze and Alessandro Gimona are all from the Macaulay Institute. We've done some work with Pete Edwards, Alun Preece, who is now in Cardiff, and Edoardo Pignotti, that was through the contacts at the University of Aberdeen on sort of grid based simulation which I'm not going to talk about. And I've also done some work with Dawn Parker in FEARLUS looking at their markets, Dawn Parker currently at GMU but about to move to Ontario I think.

Funding for this work, most of it's come from the Scottish Govt Rural Environmental Research and Analysis Directorate who are the main, the principle funding body for work at the Macaulay Institute. There's been some funding from ESRC, the National Centre for e-Social Science, that covers the work done at the University of Aberdeen, and we've had a little bit of EU money.

Work with FEARLUS breaks down into sort of numbers of projects. There are a couple of originally funded projects involving building and developing the FEARLUS model. We then did some work with some other colleagues at the Macaulay Institute, Bob Ferrier leading that on linking land use change to diffuse pollution. I'm currently working with Alessandro Gimona on linking FEARLUS with biodiversity change and as I said before, I've worked with Dawn Parker on the land market model.

The CAVES EU project was really there to explore complexity, but we as part of that work used qualitative research to sort of enhance and validate FEARLUS, I'm not going to talk about that very much in fact, though I think given some of the discussions we've had today, that may interest you, happy to answer questions on it if you like. And then some other work that I'm not going to talk about.

So just to sort of outline what I'm going to go through today, because I thought this was all about adding behaviour, I've tried to emphasise the sort of behavioural aspects of the agents in FEARLUS and just go through some of the things we've done with that. But before I do I will give you some sort of inspiration and evidence for FEARLUS, why we thought that might be a good thing to do before concluding.

So Richard Aspinall who is now chief executive of the Macaulay Institute but before he went away briefly, well for a number of years in fact to America, he did some work with Dick Birnie and at the time forestry was profitable, there were considerable incentives both in the market I think and in the Govt policy at the time to plant forestry. So what they did is they took an area of Scotland, I'm afraid I don't know which area this is but it actually doesn't matter for the purposes of demonstration, so they took an area of Scotland and using Bayesian probability mapped where they thought forestry was most likely to appear, and in this map the darker the shade of the green, the higher the probability. And this was all based on suitability for forestry in terms of climate, the gradient of the land and the soil type. But when they actually then mapped where forestry turned out to appear there were considerable areas of dark green which is where the forestry was highly suited, but no forestry had been put there. Now there could be all sorts of reasons for that, but the next step was to add ownership boundaries and you can see that there are numbers of areas where, like here for example and here, where there are landowners who have got large areas of suitable land and they've not put it up at all. And there are all

sorts of reasons behind that, such as for example wanting to maintain the land for grouse shooting among various other possible issues. So the point was that landscape pattern observed at the regional scale is a function of local interactions and individual preferences as well as market drivers, it's not all about fiscal rationality.

And here's some anecdotal evidence, there's an interesting story I came across of a farmer who is making a loss of tuppence a litre for milk and this guy has a spring on his farm which he could bottle and sell for 80 pence a litre. And he says quite explicitly, we're giving this water to the cows and devaluing it by turning it into milk! And he says like all dairy farmers we could pack up tomorrow and do something with our capital but we do it because we have an emotional investment in the land and the animals. We know that there's a market for our product if only the market worked. Now there are issues, or at least there were at the time, there are issues with the dairy market, but nevertheless I think this highlights some of the kind of issues with modelling decision making in farming, in agriculture.

So my argument would be that land manager decision making isn't entirely fiscally rational, there are multi dimension aspects, as well as wanting to make a profit which is actually part of being seen by one's peers as a good farmer, there are other aspects to being a good farmer that are very important. Another one would be keeping the name on the farm, and the questions of one's identity as a farmer. So I am a dairy farmer as opposed to an arable farmer let's say, there are a couple of papers, a very interesting read, Robert Burton another, well he's now ex Macaulay Institute and Geoff Wilson who is based in the south somewhere, maybe Southampton or Portsmouth or somewhere like that, I don't really know. So there are questions of identity, the desire to be seen by your peers as a good farmer, there are also issues of nature conservation, despite some, well a hotly contested domain shall we say?! There are many farmers who see themselves as nature conservationists and many ecologists who don't!

Another issue I wonder is whether uncertainty means utility maximisation isn't really an appropriate paradigm for considering farmer decision making. One of the issues is of course when you're a farmer you decide what you're going to do a long time before you actually get the economic return for doing it, but in the intervening time all kinds of things can go wrong. So it's very difficult to sort of put in the extra effort as it were to maximise your return, because you can't predict at the time you make that effort what that return is going to be. So that's possibly where some of these issues about getting I suppose value from your work as a farmer comes from, questions of identity, doing the job well. I mean one of the signs of being a good farmer, for example a good arable farmer is of having parallel tramlines on the fields. So the farmers will go round their neighbours' farms and they'll be looking at him going, oh you know bit wobbly tramlines there you know! There are good reasons for that because of course if your tramlines aren't parallel then you know the boom, when you're going up and down the field spraying it, you're going to either miss out areas or overlap them and spray them twice. But you know there's also stuff there about one's skill and so on.

So in sort of agent based models of land use change you often find satisficing or heuristic decision making algorithms being used and you can also use some algorithms grounded in cognitive theory, again I'll be coming on to in a minute.

Decision making can also be interactive. Now again a contentious point possibly. There is a sense in which farms see themselves as being very independently minded, but there are social influences on their behaviour, I mean I've talked about you know being seen by your peers as a good farmer, and there is some evidence for you know imitation going on, farmers giving each other advice, I mean perhaps they don't, perhaps they give each other bad advice sometimes, but you know depending on your peer group you know, I mean farmers do socialise with each other a bit and you know depending on those kind of social interactions it's reasonable I think to speak of imitation and advice going on as well as approval, and there are other social influences you might consider.

I would also argue that if land manager decision making or farm decision making was entirely fiscally rational then competition with less regulated global agricultural systems could mean bad news for some of the other things that we care about, in terms of soil degradation, water pollution, loss of biodiversity, impact on wildlife, animal welfare, landscape amenity, workers' rights, food security and even disease control. And there are probably numbers of other examples that one could think of.

So if you like FEARLUS was inspired by qualitative evidence of the nature that I am talking about. And what goes on in the model is basically a three step cycle in which the agents choose the land use, and we think of land use as being a choice of crop and management strategy all in one sort of aggregated concept. And they might bear in mind various sources of information when they make that decision, they can make that decision independently, we can do that, but we can also

configure them to bear in mind what their neighbours are doing, to bear in mind what some of the external conditions, the climatic and economic factors that influence the economic return they get. And the local biophysical characteristics of the land parcel they're choosing, they're also possibly allowed to vary. So once they've made their choice, then as per the agricultural system they get the return, and after that if you haven't got enough money you've got to sell of your land and so you have an exchange of land, and I suppose the upshot of that is a kind of evolutionary process in the farmers with more successful decision making algorithms are more likely to own more land after a period of time than those with unsuccessful algorithms.

This slide really, probably the most useful piece of information is sort of that we break with kind of strict cellular automota interpretation of neighbourhood, so if we consider this farm here, if this farmer were to use information from their neighbourhood, it would be all of the land parcels owned by neighbouring land managers rather than just the immediate cells around the cell being chosen, if you see what I mean, which is a break from strict cellular automata interpretation.

So this was the kind of way we approached the decision algorithm in the early stages of FEARLUS and again highly heuristic, we first have a kind of satisficing question, have they got enough and were they happy with what they did in the last, in the previous year? And then we have this sort of habit strategy that we plug in here, I mean we could have plugged in other ones, typically if you were happy you didn't make any change at all, and if you're unhappy then in comes the random fiddle factor, do you copy your neighbours or not? And that was just a probabilistic thing. So there's a small, there might be a chance of copying your neighbours rather than choosing a land use independently. And the one we would typically do for that is just experimenting at random with any of the land uses available. We kept the land uses fixed over time I suppose I should say, so you just have a set, a fixed choice set.

And this is the sort of thing that you get as a result. What might be going on here, and it's best just to think of the land uses in terms of colours because they're quite abstract in how they're represented, so you know the green land use of year 12 is very popular but perhaps the prevailing climatic and economic conditions are mitigating against it, and so some of the farmers are experimenting with other ones, and over time this experimentation spreads and you end up with you know people using this one. And that cycle you know goes on and on as the climate and economy, these factors influencing choice change.

Just to give you an illustration of the kind of work we've done with this, mostly it's been, most of the work with FEARLUS out there and the literature has been on imitation and experimentation on all aspects of this kind of heuristic decision making process and we might compare different decision making algorithms in different degrees of rates of change in these external conditions or in the biophysical characteristics of land, you know how similar my land is to my neighbour's land. So these provide if you like scenarios for us to explore in this relatively abstract way. And I should say, I mean to pick up on some of the points being made earlier today, we haven't drawn on data, this is more agent based modelling to explore kind of in principle questions, rather than focus on a specific problem with data. But as I've said earlier you know we've done this work in CAVES with some qualitative validation of the model and there were plans to then go and do a real world simulation, but you know with, bring in data from the outside world, you know to configure the local biophysical characteristics of the land let's say, and perhaps to configure some of the decision making algorithms of the agents, but time prevented us from doing that unfortunately.

Anyway, the sort of work that was done in the early days of FEARLUS was very much like this, we have a series of sub populations and we're interested in how they compare in some particular environment of spatial and temporal change. So we've one sub population which we'll call SI, S stand for simple and I for imitation, they basically always copy what most of the people are doing in a neighbourhood, we put a little weighting factor in there so there was a chance for them to select a less popularly used land use of small probability, but they chose a land use weighted by the number of times it's been in the neighbourhood. Then we have a more sort of intelligent imitation algorithm which has some idea of looking at what's been applied on the neighbouring land, how well that might have done in the previous year on their own land, we're able to sort of evaluate the differences in biophysical characteristics. And this is a sub population of managers where they use an aspiration threshold, so there's the question of them always being you know, they won't change if they're happy, so that's this element, there's a small probability of random experimentation, otherwise they themselves could do imitation based on how much yield each land use has generated in the neighbourhood.

The way we do things in FEARLUS, because the model has stochastic elements we would, when we want to say 'the model does this' we hypothesise, we make that as an hypothesis, we then design an experiment, we run that experiment and we

use a statistical test to confirm that the output of the model is that, should be within some acceptable level of significance, so you know where you've got a stochastic model you should report output from just one simulation, it's generally not a good idea.

So the results from these three sub populations, again this is all just for illustration of the kind of thing we did, you know was that these intelligence imitators would beat the experimenters, these would beat the sort of more wait and see what everyone else is doing imitators, but when you put these two against each other, there was no significant difference in their performance. Why might that be? Well when you put the simulate imitators against the experimenters you get this kind of patterns of land use change over time, you know this is sort of your classic Rogers innovation curve right, I mean you could see it as that, as land uses are adopted, as a reason, well bearing in mind the time steps, it would reasonably be actually quite a shallow gradient. So these imitators, these SI imitators are slower on the uptake, they wait for the land uses to become established before they're going to adopt it, and that basically means that the risk associated with experimenting with new land doesn't confer any disadvantage on those who are prepared to take it.

When the more intelligent imitators are put against these experimenters however, there's a much steeper gradient in terms of innovation adoption and so the, you get you know very rapid complete adoption over land use and then as soon as that land use becomes less cost effective and another land use is experimented with that works, it's going to be adopted very rapidly. And so these more intelligent imitators are able to exploit the risk and end up with more land.

But when you put the two imitation strategies together, because neither of them take the risk within experimentation you end up with lock in and once the locked in land use becomes non economically viable the population just completely cycles and is replaced. So that's just the sort of thing we would do. And you know we've worked on wider questions on imitation, looking at for example issues of aspiration and there's a forthcoming paper in JASSS on various ways that imitation could be implemented and comparing their effectiveness.

So this comes back to this question I raised earlier in the discussion with Edmund about how you go about implementing some of these heuristic algorithms, you've got quite a lot of choice open to you once you decide to go that way.

I thought I'd try and just relate a bit back to microsimulation. I wouldn't say we've done microsimulation but we've certainly used some microsimulation like studies to examine sort of reduced form version of FEARLUS and the kind of question that that's been addressed to is why using an aspiration threshold is an advantage in some situations? Or why diversifying land use selections can be an advantage in highly unpredictable environments. These obviously use decision making algorithms that don't involve interaction with neighbours, so it's quite well suited to the more, the very simple kind of heuristic algorithms that I was showing you earlier, not the interesting ones, and use only a small number of land parcels, again because it becomes difficult to analyse a lot of them. So basically the sort of thing we would end up with, a kind of state transition diagram, and I don't really want to go into it in any depth, I can if you like, but I suggest we come back to it if that's what you want to do. Mainly I wanted to demonstrate that we use similar kinds of technique, you can, there are sort of areas of overlap, I don't know if you'd call it overlap but yes I think there are areas overlap, I'm going to call it that, where microsimulation style techniques I think could be useful in helping to understand some of the results you're getting out of an agent based model in a reduced form. So again this is another one to explore, another question why having diversity, so these boxes here, the RS correspond to diversity rather than uniformities is more resilient in certain cases.

In more recent work with FEARLUS we've explored the question of diffuse pollution. Generally this refers to run off from fields, things like nitrates, phosphates, fertilisers and pesticides, it could be applied to airborne pollutants like pesticides and greenhouse gases, which in farming would be methane and nitrous oxide if you wanted. One of the nice things about the pollutants going into the waterways is that they can be monitored downstream, and that monitoring is less costly and only possible in fact if part of farms go over a catchment or sub catchment. So one of the questions we were interested in investigating, so again this sort of idea of in principle questions rather than a specific question focused on a particular area at a particular time, could social interactions between farmers be used to make a monitoring at the catchment scale effective in reducing pollution from agricultural run off? As I've said before farmers both compete and cooperate with neighbours and peers, they learn from what their neighbours and peers are doing, are not straightforward profit maximisers and value a good opinion of their peers, partly to be seen as a good farmer because it's a question of their identity, but also in some cases because they need their neighbours' help, you farmers often, certainly small scale farmers will help each other out at harvest time and lambing and all that sort of thing.

So refocusing on the question, under what circumstances would collectively earned payment for pollution reduction be a policy instrument worth considering? So now the sort of updated FEARLUS model has a decision process that takes into consideration social acceptability as well as estimated yield which is kind of a proxy for profit. The consequences of the decision yield both an economic return and a pollution, which is again just an abstract quantity. You've got land cells as before. We've also got social interactions in terms of neighbours' approval and/or disapproval.

Another detailed slide. So we changed the way that decision making works for this model, we used, land managers have these two things that they care about, both profit and approval from neighbours and they need a way of generating an expectation of these quantities for each decision they make. And the relative importance of these varies between land management over time. This is important otherwise you could just collapse it all into one sort of utility. But let's say you've just been disapprove of by your neighbours, assuming that you care about that, then you know maybe you'd be more willing to you know make some changes to make them happy than you would otherwise be. Equally if you've just lost an awful lot of money you might say well stuff what my neighbours I'm going, you know I've got to bring myself into the black! So we've got this changing salience according to various events that might occur and sort of coded as rules.

And then to do the decision making itself we use case based reasoning and this is a technique from cognitive science, I'll give you a bit of background in a minute. Here, land managers maintain an episodic memory or case base which stores previous decisions they've made, what the circumstances of those decisions were in terms of climate and economy and that sort of thing, and what the outcome was in terms of profit and approval. So they considered each year we've got this satisficing component in that they consider whether they're happy with their yield and their neighbours' approval and if they're satisfied they don't change, otherwise they use this case based episodic memory and experiences as a basis for choosing new land uses. And if they can't find a case then default values are used.

Now case based reasoning arose from cognitive science in the late 1970s, the principle being that knowledge gained from experience is encoded in episodic memory of scripts, in our case it was quite a simple script I suppose that I did this and this was the outcome and it allows us to set up expectations and influences. Schank and Abelson are the two authors there. And what's interesting about it is that it's supported by psychological study, so Klein and Calderwood in 1988 concluded from a study of some 400 decision by decision making experts that processes involved in retrieving and comparing prior cases are far more important in naturalistic decision making than are the application of abstract principles, rules or conscious deliberation between alternatives. Now I mean you've heard a bit about BDI and Peck from the Leeds team, again this is just another mechanism for decision making that's out there in the literature with some sort of psychological support for it in the evidence, you know it's reasonable to suppose that people make decisions in that way.

So what you end up doing is that these crosses are the expectations generated from the case base and that obviously generates a Pareto Front where there are various options that are you know better than all the others in at least, in both dimensions, but they're not better than each other, they're partially ordered. And to make a total ordering you decide which one you're going to use, you would use the salience. So which of these five options, the land manager generated these crosses from the case base they used, would depend on their salience at the time. So if they've just lost a lot of money it's going to be that one, and if they've just, everyone hates them, it's going to be that one, right, I mean that's the idea.

We explored this again using lots of runs, varying and various properties of the model. We had five land uses, which were designed to reflect the general principle that the more yield you get from your crop, the more pollution you're going to get. So there's an economic incentive to go for land use 5 but there's going to be lots of pollution from that.

And then what we have is an agent, a Govt agent, or an agent representing the Govt that wants to see your pollution kept to a certain level and have various policies they might use and what, again because we're investigating at a catchment scale, they'd monitor the total pollution across the whole catchment and if it's less than a threshold, they're going to issue a certain amount of money to all of the land managers for keeping the pollution down. Obviously that creates a social dilemma, individually you're better off if you use the polluting land use, but if everyone does that then the land, then the pollution will be too high and the Govt won't give you any cash.

So we're interested in then two aspects, how we might encode the reward mechanism and what the threshold should be and how much you should give the land managers, and then what kind of normative processes there are amongst the land managers. Again we assume, you might assume that land managers want to get the money from the Govt, I mean certainly farmers don't like it when subsidies are taken away right, so because we've created this social dilemma we would assume that land managers are going to disapprove of each other if they use the more polluting land uses, I think that evidence for that is probably not very good but that's the assumption for this model. The reason I've highlighted some of them is because in the next, the following slides I'm comparing this particular policy with not issuing a reward at all, and this particular approach to issuing you know approval or disapproval of your neighbours with no social approval at all just to demonstrate the kind of outcome you've got.

So here's the outcome looking at it in terms of pollution, from left to right you're comparing there being so social approval on the left to using the social approval function that I've said which is you disapprove of your neighbours if they're using the polluting land uses. And from top to bottom you've got reward and no reward, I mean the first thing you can see immediately is the graphs look similar on top to bottom, so there's a similar kind of dynamic going on in the model, and that certainly it's the case that if you're not issuing a reward at all, then the time at which this red line is this 2000 threshold, the time that you're spending in using this, having an acceptable level of pollution is very small. But what you also find comparing left to right is that there's a slight jump in that the social approval brings the mean level of pollution down a mile. So this means that combining the two together you are having longer periods, much longer periods of time when the pollution is below an acceptable threshold to the Govt.

And again this is reflected in land use choices, the cyan and yellow are the more profit making land uses, you're seeing those a lot more often in the landscape in these three and less frequently here, it's not that you don't see them at all, I think sometimes the Govt isn't giving them enough money to compensate them for the loss of cash or the less polluting land uses, the red and the green are really so loss making at that time that you know only an idiot would use them. So you know they don't really have a choice but to use the more polluting ones.

And we can also see how land managers are making decisions and the different ways that they're making decisions, have they got a perfect case or an imperfect case? Are they having to experiment because they haven't any case at all? Or are they using habit mode because they're happy with what's going on? And this, the green line here is when they're using habit mode and again that indicates that they're happy with both their social approval and yield. And really this is the one in which it appears the most, which is interesting.

So general observations, the larger the reward the less time land managers spent using more polluting land uses, and as we've said social approval seemed to lower the mean pollution levels, if land managers cared about neighbours' opinions and disapproved of neighbours polluting, and taken together these two were more effective than either acting separately. And the general pattern of a simulation running which the reward had an effect was the variation in pollution levels as exogenous factors changed land use's profitability and levels much above the threshold were seldom maintained for long periods when this was working.

However, the particular algorithm we used to either do the reward or have the social approval made a difference to the size of the reduction effect, I imagine the results I've just showed you were the most favourable.

Just to move on, there were some other areas of decision making in FEARLUS and we've got an advice model which is when agents don't have a case, they can ask their neighbours for one and I've used this in the recent work with Alessandro Gimona on biodiversity but we've not really adequately explored that phenomenon. And with Dawn Parker we've been land market decisions. As soon as you say that there's not going to be optimising decision making you then have to provide answers to the questions that that assumption answers for you. So when to sell when do you buy, what do you sell, what do you buy, what price to accept, what price to offer, what is the final sale price, all these questions are answered by you know the kind of standard neoclassical models of markets, and once you want to sort of move away from those assumptions you have to answer them yourself. And the decisions you make about these questions affect the outcomes in the model.

So to conclude, agent based modelling doesn't constrain your assumptions about decision making to optimisation, maximisation, fiscal rationality and non interactive behaviour. You can base decision making in agent based modelling on cognitive theory, so you can still have a sound academic basis, a scientific basis perhaps for your, for the way in which the

agents make decisions. But the results can be affected by the different algorithms you use to influence behaviour, and one of the things I guess we do in FEARLUS is to explore the alternatives which is maybe the kind of thing that Leeds was showing us with their multiple modelling framework, I can't quite remember the acronym but you know they're also seeing the importance of swapping in and out these alternatives to explore them.

And I suppose what I wanted to point out, the bleeding obvious really, is that the assumption of optimisation or rationality or non interactive is still an assumption and mathematical tractability isn't an excuse for failing to look at formulae, and formulae I mean in the sense of using computers, you know, running a computer programme is in some senses conducting a proof, you know logic, you're just using, logic is the basis of your formulae rather than let's say calculus or other processes used, as other assumptions and algorithms.

And that's it. So any questions or issues you want to raise?

QUESTIONS

Male question 1 –random selection over a set of values qualitatively plausible? Or is it the case that people suddenly stop growing wheat and start planting strawberries?

Gary Polhill – I don't think it's plausible over the complete set of land uses because of this question of identity. But I do think there is an element to which farmers will experiment. I mean from, what I should say is I'm not a qualitative social scientist but I talk to the qualitative social scientists at the Corn Institute who go out and interview farmers and I'll often ask them to ask things. Farmers will sometimes say oh you know this wasn't working, what am I going to try now? I don't know, yeah they might even say …

Male question 1 – Something really different.

Gary Polhill – Yeah they may well do that. Often what they will do, I mean interesting landscape features, often what they will do is hide the fact that they're experimenting with something by putting it in the middle of their farm rather than using it in the fields at the edge of the farm that farmers might drive by and see what's going on, and that's the kind of phenomenon we haven't captured in the model. But there is certainly qualitative evidence for that sort of behaviour. And you know then again if the experiment doesn't work they won't do it. But they won't sort of wholesale adopt some completely new process. There are other sort of impediments to adopting completely new land uses and particularly if they require new machinery or infrastructure, you know I mean like you know you wouldn't take an arable farm necessarily and immediately convert it to dairy because then you've got to have the dairy sheds and the milking equipment and all this kind of stuff. So there are complications.

Male question 2 – Two questions if I may, one is the examples that you showed of maps of different land uses, what happens with edges? Is this effectively treated as an island with no neighbours in the final picture?

Gary Polhill – Yes so you were looking back at, this is horribly slow (clicking), the evolution, that map, it's sort of easier if I point at it. I don't know why this has gone so slow, there you go. Yeah, in fact what we might do is even have a toroid. So this cell would be a neighbour of that cell and this cell would be a neighbour of that cell. But we can also, we could simulate, we can now simulate catchments, particular catchments, so you could let's say simulate some island or other. Outside influences on decision would be more difficult to simulate I think yeah we wouldn't do that. So what was your second question?

Male question 2 – The second question was answered by what you were saying. This is assuming that the area represented is a small part of some wider system and so the you know choice of land, the choice of agricultural production doesn't include affect the prices.

Gary Polhill – That's right yes.

Male question 2 – The implication here is that the demand for the product in light green has gone down and the fact that there's only four people producing it here it's going to fly back up again.

Gary Polhill – Yes that's right, absolutely right.

Male question 3 – Why do you choose the sides to be toroidal rather than 2D?

Gary Polhill – That's because we don't want there to be, again for the purposes of answering the question that we have we don't want there to be boundary effects in the model. So you want, this kind of standard practice in cellular automata modelling sometimes is to use this so that every cell has the same physical neighbourhood, so the neighbours of this cell, this cell has let's say, we were just considering 8, this cell has 8 neighbours around here and so does this cell. If you slice it off, this cell in the corner only has 3 neighbours and then edge cells have 5 and so …

Male question 3 – If the application was a geographical location?

Gary Polhill – If it was a geographical location you wouldn't do that because obviously the real world isn't a doughnut, yeah!

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