Formalising the consumat in an ecological-economic model

Many integrated models have been developed to study the dynamics of natural systems. As was concluded in Chapter 1, human behaviour is an important factor determining such dynamics, because natural resources are often being (over)exploited. However, integrated models usually formalise human behaviour according to the rational-actor approach, which is not capable of incorporating processes of social comparison, imitation and habit formation (see Chapter 1). As these processes are highly relevant in the context of resource management, the consumat approach was developed to provide a psychologically rich model of human behaviour, that can be applied in the context of integrated modelling. In the previous chapters the consumat approach has been tested in relatively simple environments. The present chapter is aimed at testing the applicability of the consumat approach in connection with a more complex ecological-economic model. Moreover, it is being investigated to what extent variations in micro-level processes seriously affect macro-level outcomes. To demonstrate the effect of micro-level variations, in the simulation runs to be reported a *homo economicus* and a *homo psychologicus* are being formalised. The *homo economicus* is formalised as a consumat that engages purely in deliberation, and it thus resembles the rational actor, whereas the *homo psychologicus* has all four cognitive strategies at its disposal. These consumats are placed in the ecological-economic model of Lakeland (see below), and their behaviour is being contrasted so as to demonstrate the effects of variations in behavioural processes at the micro-level.

**Lakeland**

“Lakeland” (De Greef and De Vries, 1991) is a relatively simple ecological-economic model, which comprises two natural resources: a fish-stock in a lake and a nearby gold-mine. The lake is being modelled as a simple ecological system of fish and shrimps. The quantities of fish and shrimp are being modelled as a set of Lotka-Volterra equations simulating a predator-prey system (Lotka, 1925; Volterra, 1931). As an addition, the shrimps are being made susceptible to the pollution of the lake. The pollution is not only concentrated in the water, but also in the sediment of the lake, from which it may be released when the pollution concentration of the water drops.

The introduction of consumats in Lakeland implies that different behavioural processes, such as social comparison and imitative behaviour, underlie the consumats’ harvesting behaviour. Sixteen (16) consumats are being placed in Lakeland, and these consumats catch fish from the lake to satisfy their need for food. Moreover, they may also export fish, and the returns can be spent on assets such as luxury goods. Import of fish from an international market is also allowed. If the gold-mine is opened, consumats may also dig for gold. The money that is earned by mining can be spent on fish imports and/or on luxurious assets. The consumats thus may engage exclusively in mining, thereafter buying fish for food. The pollution that is caused by mining is reducing the carrying capacity of the lake for the fish and shrimp populations. The consumats determine how they allocate their time on leisure, fishing and mining. They are equipped with abilities for

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13 This chapter is based on Jager, Janssen, De Vries, De Greef and Vlek (in press)
fishing and mining, and they want to satisfy their four needs: leisure, identity, subsistence and freedom. These needs are selected out of the larger set of needs as distinguished in the conceptual model (Chapter 5). It is assumed that the satisfaction of the leisure need relates to the share of the time spent on leisure. The identity need is satisfied by the relative amount of money the consumat owns in comparison to consumats with similar abilities. The subsistence-need relates to the consumption of food. The need for freedom is assumed to be related to the absolute amount of money the consumat owns, which can be spent on whatever (luxurious) assets the consumat prefers (autonomy). These assumptions are of course very crude, but they allow us to formalise different needs in a simple manner.

Figure 9.1 depicts the variables used in this simulation model in the framework of the conceptual behaviour model as presented in Chapter 5 (Figure 5.5).

Figure 9.1. The variables used in the simulation model placed in the schematic representation of the conceptual meta-model of behaviour (Figure 5.5). The white lines refer to feedbacks within the consumat.

To study how the different possible behavioural processes may affect the interactions with the simulated environment, it was decided to focus on experimental manipulations of consumats’ supposed tendency to engage in particular behavioural processes, thus contrasting the homo economicus with the homo psychologicus. These experiments were performed in two set-ups of Lakeland, one in which only fishing is allowed, and a second
in which mining is allowed besides fishing. First the results obtained with Lakeland where only fishing is allowed will be described, and in a next section the results of introducing mining in Lakeland are presented.

**Fishing in Lakeland**

In the first simulation experiments the set-up of Lakeland does not allow consumats to dig gold, and thus they fully depend on their fishing capacities to satisfy their needs. Varying the minimal level of need satisfaction and the level of uncertainty tolerance allows for the specification of consumats that engage in one or more of the four behavioural processes distinguished in Figure 9.1. Two types of consumats have been formalised to show how different types of behaviour affect the management of the fish-stock. The first type is relatively quickly satisfied but also quickly uncertain (LNSmin = 0.05, UT = 0.05). This leads this type of consumat to engage in all four behavioural strategies. This consumat, having a large degree of freedom regarding the behavioural strategies, will correspondingly be denoted as the *homo psychologicus*.

The second consumat type is virtually never satisfied or uncertain (LNSmin = 0.95, UT = 0.95). This causes this type of consumat to engage exclusively in outcome-optimising deliberation. This consumat can be considered as a simple version of the optimising agent in economic models, and it will consequently be denoted as the *homo economicus*. The *homo economicus* is self-supportive, i.e. not learning from the behaviour of other consumats nor making explicit assumptions about the decisions of others. The consumats employ a time-horizon (cognitive ability) of 10 time-steps when engaging in reasoned processing (deliberation and social comparison). Moreover, the consumats have a fishing ability of 6600, indicating that they are capable of catching 6600 units of fish per time-step when the fish-stock is on its carrying capacity level (the maximum number of fish-units is about 23000). Factors that affect the actual catch are the fish-density (in our model 0.000002 when the fish-stock is maximal, indicating that there is an occasional fish in the water), the fish growth function (in our model about 2.3, indicating that each time step the number of fish is multiplied by 2.3 for as long as the maximum is not reached) and the length of the fishing season (in our model .80 of the time). Consequently, we have a very viable fish-stock, which renews itself very quickly, and hence is quite difficult to deplete.

To introduce environmental uncertainty in the model, a stochastic function in the fish catch has been formalised. For both experimental conditions (*homo economicus* and *homo psychologicus*) 100 model runs have been performed, for which the average outcomes will be presented. Each experiment involved 16 identical consumats inhabiting Lakeland. Thus, all consumats were either *homo economicus* or *homo psychologicus* depending on the experimental condition. The consumats start with an equal financial budget. Because they are depending on each other regarding the management of the resource, the consumats are actually caught in a commons dilemma.

In reporting the results we will focus on a few essential variables. First, the behaviour and behavioural processing of the consumats will be observed. Second, the developments in the fish-stock will be considered. Third, the developments in the need satisfaction of consumats will be observed. Finally, attention will be given to the developments in the financial budget of the consumats, which provides a material index of welfare in the model.
Each simulation experiment involves 50 time-steps, in which consumats have to decide how much time to spend on fishing and leisure in order to satisfy their needs.

**Results**
Looking at the behavioural processes the consumats engage in, it appears that the *homo psychologicus* engages in all four behavioural strategies, as was intended. Figure 9.2 shows for time-step 1 to 50 the proportion of time each behavioural process is engaged. These results are an average outcome of 100 simulation runs under the condition of all consumats being *homo psychologicus*.

![Proportional distribution of the four behavioural processes for the *homo psychologicus*](image)

The sudden shift from much repetition to much deliberation at $t \approx 18$ is caused by the fact that the initial financial budget, that the consumats use to buy luxury goods or to import/buy fish, has depleted around that time. This worse financial situation causes the consumats to be dissatisfied more often, causing them to engage in deliberation more often. Because the consumats are occasionally uncertain and hence engage in social processing (imitation and social comparison), this decrease in need-satisfaction also causes the relative high proportion of imitation before $t = 18$ to change towards social comparison (see Figure 9.2). The *homo economicus* engaged purely in deliberation, as it was defined to do.

Figure 9.3 shows the development in time of the fish-stock for these two conditions (100 simulation runs per consumat-type condition). It can be observed that the fish-stock depletes for the *homo economicus* and remains at a high level for the *homo psychologicus*.
FORMALISING THE CONSUMAT IN AN ECOLOGICAL-ECONOMIC MODEL

Figure 9.3: The development of the fish stock in time for the two consumat-type conditions

These effects can be attributed to the proportion of time spent fishing, which is graphically depicted in Figure 9.4. *Homo psychologicus* slowly increases its fishing to 0.7 of the time, whereas *homo economicus* more rapidly increases its fishing to 0.8 of the time. The explanation of these effects will be done below in two separate sections for the *homo psychologicus* and *homo economicus*.

Figure 9.4: The proportion of time spent fishing for the two consumat-type conditions

Differences in time spent fishing have consequences for the financial budget of the consumats. Figure 9.5 shows that the higher proportion of time spent fishing by *homo economicus* yields a higher financial budget during the first 35 time-steps. However, starting from the moment that the fish-stock gets depleted, the financial budget of *homo economicus* quickly drops to zero. For the *homo psychologicus*, a decline of the initial financial budget can be observed, until a relatively stable budget is reached that is purely earned by fishing.
Homo psychologicus
As was shown in Figure 9.2, during the 100 experimental runs the *homo psychologicus* engages in all four behavioural strategies. Consumats start fishing for 60% of the time (initial setting). An occasional bad catch may yield a lower financial budget in comparison to other consumats. As a consequence, this consumat’s level of need satisfaction for ‘identity’ drops below the critical level, causing it to engage in reasoned processing (deliberation or social comparison). When deliberating, this consumat will increase its time spent fishing to about 80% (while the satisfied consumats remain at 60%) to increase its financial budget. This is mostly a satisfactory action, and as a consequence this consumat will continue to process automatically. This implies repetition of its own previous behaviour, or imitation of the behaviour of similar consumats. The latter may cause the consumat to decrease its time spent working again. Other satisfied consumats may simply imitate the increase in time spent working without ever engaging in reasoned processing. However, most of them remain fishing for 60% of the time. In some runs, however, the number of consumats that imitate the increase in time spent fishing is so large that the resource gets seriously depleted. This causes the slightly downward development of the fish-stock beyond step 36 that can be seen in Figure 9.3. On the average, the proportion of time the consumats spend fishing increases to about 67%.

The consumats that increase their time spent fishing will be more likely to catch a surplus of fish that they can sell on the market. This allows them to earn some money for luxury products, which satisfies their need for freedom. Moreover, their level of need-satisfaction for identity is relative high because they have more money than the consumats that did not increase their time spent fishing. However, the increase in time spent fishing is not that large that their level of need-satisfaction for leisure drops significantly. Finally, they catch enough fish to satisfy their need for subsistence. Because the needs of the consumats that increased their time spent fishing are staying at a sufficient level, they experience a high general level of need satisfaction, causing them to remain processing in an automatic manner. This implies repeating their own previous behaviour, or imitating the behaviour of similar consumats.

The consumats that did not increase their time spent fishing in the beginning (say, the first 15 time-steps) will catch somewhat less fish, using it exclusively for their own consumption. Not selling fish on the market implies that their financial budget declines, which causes the over-all decline of financial budget for the *homo psychologicus* condition (Figure 9.5). As a consequence, these consumats cannot afford to buy luxury goods at a
given moment in time. Because of that, their need for freedom decreases below the critical level around \( t = 20 \), causing them to deliberate and socially compare regarding better opportunities. However, often they calculate that increased working may increase their level of need satisfaction for freedom, but at the cost of their level of need satisfaction for leisure and identity. Despite the fact that they remain dissatisfied as regards freedom, they do not change their behaviour because there is no other behavioural opportunity yielding a higher over-all level of need satisfaction.

In most cases the consumats have a reasonable level of need satisfaction for subsistence, identity and leisure and a low level of need satisfaction for freedom. In about half of the simulation runs a subgroup of consumats increases their time spent fishing in an early stage, resulting in a higher level of need satisfaction for freedom in the long run.

To obtain an indication of distribution of income, Lorenz (1905) and Gini (1912) developed income-disparity indexes. The Gini index (Gini, 1912) is a measure for distributional equality, and provides a macro-level indicator of economic equality in a society. In the simulation experiments, the Gini index is being used to indicate financial equality. A Gini index of 1 denotes complete financial equality, a Gini index of 0 complete financial inequality. In the experiments with Lakeland the consumats all start with an equal financial budget, which implies a Gini index of 1.0. In the first 20 time-steps a drop to about 0.20 was observed. After this sharp decline in the Gini index, in about half of the simulation runs an increase towards 1.0 can be seen, whereas the other half shows an irregular pattern, oscillating between 0.20 and 0.30. This oscillating pattern occurs in the simulation runs where a group of consumats increased their harvesting behaviour in the early time-steps because they experienced 'bad luck' regarding their harvest. Moreover, some consumats not experiencing this 'bad luck' may still increase their time spent fishing because they imitate the consumats that had 'bad luck'. Especially this last group of consumats will earn a lot of money. Because the consumats that increased their time spent fishing earn more money than the other consumats, the Gini index remains low, indicating distributional inequality.

**Homo economicus**

*Homo oeconomicus* which is never satisfied and never uncertain, exclusively engages in deliberation. The consumats in this condition immediately increase their time spent fishing to maximise their outcomes. Despite the fact that the consumats, having a time-horizon of 20, anticipate the collapse of the fish-resource, they continue fishing intensively. Around time-step 40, the fish-stock has depleted and the level of need-satisfaction of the consumats drops to 0.0. This situation typically resembles the tragedy of the commons, showing that behaviour following individual rationality may lead towards a collective disaster. The consumats implicitly ‘expect’ that all other consumats will continue their over-harvesting. Consequently, each consumat ‘realises’ that their individual behaviour hardly affects the depletion of the resource. Following the principles of individual rationality, all consumats consider a high harvesting level as optimal, and consequently they do not succeed in reducing their harvest to a more sustainable level. This situation resembles a sort of self-fulfilling prophecy, as the fish-stock depletes because the consumats expect it to deplete. This outcome is a typical example of what happens if no property rights exist on an exhaustible resource and the fishermen behave in an own-outcome maximising manner.

Using the same decision rules for a single ‘meta-actor’ with needs and abilities that are 16 times as large as those of each of our 16 consumats, would result in the meta-actor decreasing its harvesting now so as to maximise its outcomes over the forthcoming 20
time-steps. This is due to the fact that it has full control over the fish-stock because it is not being confronted with 15 other consumats.

In the condition of the *homo economicus* the consumats earn an almost equal amount of money for as long as the fish-stock is not depleted, resulting in a Gini index of about .97. When the fish-stock is depleted at around $t = 40$, and consumats' income has dropped to 0, some consumats will run out of money earlier than other consumats do, causing the Gini index to drop to a level of .60. Very quickly all consumats have finished up their finances, and this equal financial situation for all consumats obviously yields a Gini index of 1.0.

**No variation in fish-catch**

Some variations of the default case have been performed to assess the sensitivity of several crucial assumptions. In the previous experiments, the harvest of a single consumat at a given time-step was partly dependent on chance, just like any real-world fisherman may have lucky days and bad days. In the present condition, all random variation in the fish catch of the consumats has been eliminated. For the rest, the previous experimental consumat-type conditions (*homo economicus* and *homo psychologicus*) are being replicated. Removing random variation now causes the *homo psychologicus* to be certain all of the time, which would cause it to engage exclusively in individual processing (deliberation and/or repetition). Because the *homo psychologicus* does not experience occasional 'bad luck' regarding the harvest, its level of need satisfaction remains at a satisfactory level. Consequently, the *homo psychologicus* engages only in repetition, fishing for 60% of the time instead of increasing the time spent fishing to about 67% as found in the previous experiment that included a stochastic function in the fish catch. These results, showing an increase in harvesting when uncertainty increases, are in accordance with the results obtained with a simple resource (see Chapter 7). The *homo economicus*, however, did not alter its harvesting behaviour in response to removing all random variation in the fish catch. This is due to the fact that the *homo economicus* has a high tolerance for uncertainty ($UT = 0.95$), and thus is less sensitive to variations in the harvest.

**Introducing mining in Lakeland**

In the next series of experiments the set-up of Lakeland allows the consumat to engage in mining starting from the first time-step. Consumats thus can alternately fish and mine to satisfy their needs. Besides a fishing ability of 6600 (see previous section), the consumats have a mining ability of 100, indicating they are capable of harvesting a maximum of 100 units of gold per time-step. It depends on the market dynamics (e.g. world fish-price versus local fish-price) how much fish they can buy for a unit of gold. As a starting condition, the consumats are fishing for 60% of the time, and they do not yet engage in mining. For the rest the design of two consumat-type conditions as used in the first series of experiments is being replicated. Because the mining of gold induces pollution of the lake, which in its turn affects the fish-stock, data on the development of pollution concentration in the lake will also be presented.

**Results**

Figure 9.6 shows the time spent fishing and mining for *homo economicus* and *homo psychologicus* respectively. It can be seen that *homo economicus* very quickly switches to mining, but instead
of a smooth transition an oscillating pattern between time spent fishing and mining can be seen. *Homo psychologicus* shows a slow increase in mining, until at about $t = 20$ the transition is completed.

Looking at the consequences for the fish-stock (Figure 9.7), first it can be observed that for *homo economicus* the fish-stock does not fully deplete within 50 time-steps, as it did in the previous condition (Figure 9.3). The introduction of mining implies that the consumats spent less time fishing. Because *homo psychologicus* spends less time fishing than *homo economicus* the latter depletes the fish-stock to a larger extent. However, *homo psychologicus* depletes the fish-stock at a higher rate than in the previous condition, despite the fact that it spends less time fishing. A major reason for this is that the slow but persistent move towards mining increases the pollution that causes the fish-stock to decrease (Figure 9.8). This further accelerates the transition to mining, as the fish catches per hour keep decreasing.

Due to the mining, the consumats are capable of earning more money than in the previous condition without mining. As Figure 9.9 shows, this yields a higher financial budget for both types of consumats than in the previous experiment (Figure 9.5). Continually deliberating, *homo economicus* succeeds in attaining a higher financial budget than *homo psychologicus*.
**Figure 9.9.** The financial budget for the two consumat-type conditions

**Homo psychologicus**

*Homo psychologicus* shows a transition from a fishing society to a mining society. In the first time-steps some consumats may have bad luck and harvest such a small number of fish that they become dissatisfied. Because this will cause them to engage in deliberation, they perceive mining as a satisfactory alternative opportunity. At about \( t = 18 \) more consumats become dissatisfied and start mining. The more consumats engage in mining, the larger the chances are that uncertain consumats that are fishing will also start mining on the basis of imitation or social comparison. At that moment the transition from a fishing society to a mining society becomes manifest. Occasionally a mining consumat may engage in fishing for a few time steps on the basis of imitation. However, this will usually lead to dissatisfaction within a few time-steps, and the consumat will go mining again. Nevertheless, imitation causes that in some simulation runs always a few consumats remain fishing. At the micro-level a lot of behavioural change occurs in the working behaviour of *Homo psychologicus*. At the macro-level a decrease can be observed in the Gini index from 1 at the start to about .25 at \( t = 20 \). After the transition to a mining-society, the Gini index rises again to a level of about .80, indicating that income differences between consumats have decreased as a consequence of them all engaging in mining.

**Homo economicus**

The oscillating pattern demonstrated by *Homo economicus* (cf. Figure 9.6) is caused by the fact that all 16 consumats change their behaviour at the same time. This repetitive switching between more mining/less fishing and more fishing/less mining may be explained by the fact that each consumat, being in the deliberation mode, has been formalised so as to expect that all others will behave as in the previous time-step. The consumat thus deliberates that when all others increase their time spent mining, increasing the time spent fishing may yield the highest outcomes, and vice-versa. However, all the consumats reason in this direction at the same moment, and as a consequence, they all end up doing about the same in the same time-step. Over time the extremes in these oscillations converge, indicating that in the long run a more stable working time distribution is likely to emerge. Because all the consumats behave more or less the same, the Gini index remains at a level of about .99, indicating that the incomes of the consumats are almost equal.
Introducing diversity in consumats’ abilities

In the previous experimental conditions all consumats in both consumat-type conditions had equal abilities regarding fishing (6600 fish-units per time-step) and mining (100 units of gold per time-step). However, in real life a differentiation in abilities can easily be observed. The multi-agent approach makes it very easy to formalise consumats having different abilities. The central question is how such a differentiation affects the behaviour of the consumats and the ecological-economic system as a whole. To formalise this, the consumats are equipped with differing fishing and mining abilities. Four different levels of fishing ability and 4 different levels of mining ability make 4 * 4 = 16 different ability settings, thus equipping each consumat with a unique set of abilities. As settings, the average is rather arbitrarily chosen to be equal to the previous experimental conditions, the consumats with the highest ability having twice as much ability as the consumat with the lowest ability. Table 9.1 shows the design with respect to the allocation of the two abilities to the 16 consumats:

<table>
<thead>
<tr>
<th>Fishing ability</th>
<th>Mining ability</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>8800</td>
<td>67</td>
<td>Consumat 1</td>
<td>Consumat 2</td>
<td>Consumat 3</td>
</tr>
<tr>
<td>7333</td>
<td>89</td>
<td>Consumat 5</td>
<td>Consumat 6</td>
<td>Consumat 7</td>
</tr>
<tr>
<td>5867</td>
<td>111</td>
<td>Consumat 9</td>
<td>Consumat 10</td>
<td>Consumat 11</td>
</tr>
<tr>
<td>4400</td>
<td>133</td>
<td>Consumat 13</td>
<td>Consumat 14</td>
<td>Consumat 15</td>
</tr>
</tbody>
</table>

Table 9.1. The design of 16 consumats with different fishing and mining abilities

As in the previous experiments, the average mining ability is 100 gold units/time-step and the average fishing ability is 6600 fish-units/time-step. The consumats will socially compare to or imitate only the behaviour of approximately similar other consumats. In the present experiment, the similarity is expressed in two variables: level of need satisfaction for subsistence (LNSs) and financial budget. Hence, if consumats are engaging in social processing, they compare themselves with consumats having about the same quantity of food and money. Regarding food, the consumat considers other consumats having 30% more or less food as similar to themselves. Regarding money, this percentage is set at 20%. Formalising similarity on the basis of changing variables implies that the group of consumats whom a consumat compares with may change continually, depending on its own state and the state of other ‘similar’ consumats. Again two consumat-type conditions are created to contrast homo economicus and homo psychologicus.
Results

The results of this experiment are depicted in Figure 9.10. These results look very similar to those of the previous experiment (Figure 9.6). However, closer observation shows that in case of homo psychologicus the transition from a fishing to a mining society takes more time, starting earlier and ending with the consumats spending more time fishing than in the previous experiment with equal abilities. This quicker start of the transition is caused by the consumats with a low fishing ability and a high mining ability, which will be quickly dissatisfied because of their low fish-catch, and then perceive mining as a more attractive opportunity. In contrast, the consumats with a high fishing ability and a low mining ability are more likely to continue fishing, causing that at t = 50 the time spent fishing is about twice as large as in the previous experiment. As a consequence, the average fish harvest of a population of consumats having unequal abilities is larger than the harvest of a population of equal consumats. In other words, harvesting behaviour is differentiated depending on differing abilities.

![Figure 9.10. Time spent fishing and mining for the two-consumat-type conditions with consumats having unequal abilities](image)

Looking at the consequences for the fish-stock (Figure 9.11), it can be observed that in the beginning the fish-stock depletes more rapidly in the condition of homo economicus (see further below).

![Figure 9.11. The fish-stock for the two-consumat-type conditions for t = 1 to t = 50](image)
However, despite the fact that *homo psychologicus* spends less time fishing, after time-step 43 the fish-stock depletes more strongly than in the case of *homo economicus*. This is caused by the fact that the intensive mining by *homo psychologicus* pollutes the lake, which causes the fish-stock to further decrease.

Due to the pollution of the lake (Figure 9.12), the fish population decreases, and also the average catch decreases. This will make mining a relatively more attractive opportunity, and it may thus stimulate consumats to go mining. Even when the pollution causes the fish-stock to collapse, consumats can satisfy their needs by importing fish. It can easily be imagined that in such a case the eventual depletion of the gold mine will leave the consumats with no opportunity at all to satisfy their needs.

![Figure 9.12. The pollution concentration for the two consumat-type conditions for t = 1 to t = 50](image)

**Homo economicus**

Looking at *homo economicus*, two major differences with the equal abilities experiment (Figure 9.6) can be seen. First, the oscillating pattern dissipates more quickly in the unequal abilities experiment (Figure 9.10). This is due to the fact that the consumats do not behave equally because they all have different abilities. The resulting behavioural diversity causes that each consumat has less extreme expectations regarding the average time spent working of the other consumats. This in its turn causes the consumats to behave less extreme for themselves. As a consequence, the oscillations in time spent working converge, thereby further stabilising the expectations, and hence the time spent working. The second difference with the equal abilities experiment is that the times spent fishing and mining are lower. Due to this effect the fish-stock is depleted less severely at time-step 50 than in the condition with equal abilities. The explanation for this is that consumats with a high ability do not want to harvest as much as they are capable to, and the consumats with a low ability are not capable to harvest as much as they want to. Consequently, the consumats’ ability is not linearly related to their actual harvesting behaviour.

**Homo psychologicus**

In contrast with *homo psychologicus*, for *homo economicus* the average harvest of a population of consumats having equal abilities is larger than the harvest of a population of unequal consumats. These results demonstrate that an increase in the diversity of consumat abilities may have different effects on the sustainability of a system, depending on the behavioural
processing the consumats engage in. Apparently the effects of increasing diversity are not unidirectional, which emphasises the need for more research to investigate the role of diversity in resource management situations.

The introduction of diversity has an impact on the equality of the income of consumats. In Figure 9.13 the Gini index is presented for *homo oeconomicus* and the *homo psychologicus*, both for equal abilities and for unequal abilities. It comes as no surprise that adding variance in the consumat abilities causes the Gini index in general to be lower than in the no-variance condition. Logically, more variance in ability results in more variance in income. Moreover, it can be observed that *homo psychologicus* generally displays a lower Gini index than *homo oeconomicus*, indicating that non-outcome-optimising behavioural processing strategies contribute to diversity in behaviour and in resulting income.

![Figure 9.13. The Gini index for equal and unequal abilities](image)

For *homo psychologicus* with equal abilities the relatively quick transition from fishing to mining causes a relatively short period where the one consumat is fishing, whereas the other consumat switches to mining. This yields large income differences concentrated in a short period of time, which is being reflected in the sharp drop in the Gini index around time-step 20. In the condition of *homo psychologicus* with unequal abilities, the diversity in income is larger on the average, as can be seen from Figure 9.13. However, because the transition is not as complete as in the equal-abilities condition, and less compressed in time, there will be no short period of time where the diversity of income is being concentrated. Apparently, a faster transition leads to larger income differences among consumats.

### Introducing learning and technological innovation

The following experiment introduces technological innovation and learning by consumats to increase their harvest of fish. Here, mining is not allowed, making the consumats again fully dependent on the fish-stock for the satisfaction of their subsistence, identity and freedom needs. It is assumed that technological innovations only emerge when a consumat is deliberating. During deliberation there is a random chance that the consumat detects a new fishing opportunity that yields more fish per hour fishing. This is being formalised as an increase in fishing ability. This increase in fishing ability resembles a
technical innovation, e.g., engines with more power or better fishing nets. Once a consumat adopts a new technology, the other consumats can also adopt the new technology by deliberation, social comparison or imitation. In this condition all consumats start with equal abilities. Regarding fishing, they start with an ability to catch 6600 fish-units per capita. Two types of innovations have been experimentally tested, namely small technological innovations, implying an increase of 100 fish-units in fish catch per capita, and large technological innovations, implying an increase of 200 fish-units in fish catch per capita. Again two consumat-type conditions are created to contrast *homo economicus* and *homo psychologus*.

**Results**

Figure 9.14 shows the development of the fish-stock for *homo psychologus* and *homo economicus* given the two types of innovation.

![Figure 9.14. The fish-stock under conditions of small and large technological innovations](image)

In the case of *homo economicus* and large technological innovations, the fish-stock collapses very fast because of the fast dissipation of new technology. If a single consumat discovers a new innovation, the next time-step all other consumats will also be aware of this innovation. In case of small technological innovations, the collapse occurs somewhat later. In case of the *homo psychologus* it can be observed that the fish-stock starts decreasing relatively late. This is due to the fact that the consumats (easily satisfied) do not engage in deliberation that often, and consequently have a smaller chance of detecting an innovation. Moreover, due to the fact that many consumats engage in repetitive behaviour for considerable periods of time (because they are satisfied and certain), they remain unaware of the innovation. This causes that the dissipation of the innovation through the population of consumats proceeds at a slower rate.

These experiments indicate that technical innovation which increases the productivity by which resources are exploited may significantly affect the depletion rate of a resource. It also suggests that the rate at which this happens is strongly tied to the social conditions under which innovations may be diffused.
Conclusions

In mainstream economy, the behaviour of man in relation to renewable resources is traditionally formalised following the ‘rational actor’ approach. In this approach, usually large aggregates of people are represented by a single, rational actor with perfect foresight and a single, individual set of preferences. As has been demonstrated in this chapter, the consumats in Lakeland will follow different behavioural strategies depending on their own situation and the situation of the environment. The ‘deliberating’ consumat, which has been denoted as *homo economicus*, closely resembles the ‘rational actor’, only with this difference that 16 consumats have been formalised instead of a single actor. The deliberating consumat includes the notion of maximising one’s own insatiable needs within a finite time horizon with a positive discount rate and no direct comparison with other agents (see Chapter 6 on deliberation). Obviously, this is a quite narrow rationality from a larger system’s perspective and the deliberating agent might well extend its rationality to include a broader system perspective - which is what governments are assumed to do.

In this chapter, however, the focus is not on an extension of the rational actor but instead on social comparison, imitation and repetition as supplementary strategies for the individual agent. Our simulation experiments demonstrate that switching between these strategies, as is the case with *homo psychologicus*, may significantly alter the temporal development of macro-system variables such as the fish resource and consumats’ average income. More importantly, it explains such macro-behaviour in a way which is totally different from an explanation derived from a macro-model that has been parameterised so as to reproduce the same time path. The consumat model, for instance, uses exchange of information among agents as an important explanatory variable, and it can consequently suggest policy actions that are related to this information exchange. Also, the consumat model allows for the calculation of quasi macro-variables such as income distribution. This provides an interesting heuristic to explore hypotheses between (in)equality and (economic) growth. In successive experiments it would be of interest to follow the recommendation by Kumar, Gore and Sitaramam (1996) of studying the volume of poor people, the severity of the poverty and the distribution of poverty in combination. This would draw a more profound perspective on distributional equity and the behavioural dynamics affecting it. Moreover, it would be interesting to equip the consumats with cultural perspectives (e.g., Thompson, Ellis and Wildavsky 1990) or basic orientors (Bossel, 1996; Krebs and Bossel, 1997) and explore how these co-determine the dynamics of ecological-economic systems.