Modelling the Impact of Market Imperfections on Farm Household Investment in Stand-Alone Solar PV.

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Abstract

In many Sub Saharan Africa countries, access to electricity to electricity is very low in rural areas. For example in Ghana only 27% of rural households have access. However, extending the grid in these countries faces significant technical and financial constraints and many see decentralised systems particularly those using renewable energy as being enormously important. This presupposes the adoption of standalone technologies by a large number of poor farm households who are currently off-grid is likely. However, such households in LDCs typically face a range of market imperfections in credit, product and other markets. This paper explores the potential value of access to electricity for poor agricultural households and the extent to which credit and output market imperfections may inhibit the uptake of stand-alone solar panels using a life cycle farm household simulation model which allows for credit constraints and yield risk.

Introduction

According to the International Energy Agency (IEA, 2010), over 1.6 billion of the world's population mostly living in rural regions of developing countries have no access to electricity. Access to electricity has been shown to have significant benefits for rural inhabitants. At a household level, the value of access to electricity to the household is derived from a number of sources. The consumption of goods and services which are not possible without access to electricity provide direct utility, e.g. electric light, mobile phones, plus indirect potential health benefits. There are also impacts on human capital which may improve labour productivity in the long run, e.g. via extended study and work hours due to the availability of electric light. On the farm there are potential effects with at least some evidence that access to electricity improves productivity and may, via improved communication through mobile phone use, reduce farm gate price dispersion and hence improve overall farm household welfare (Barnes, Peskin, and Fitzgerald 2003;Khandker 1996).

In many Sub Saharan Africa (SSA) countries, access to electricity to electricity is very low in rural areas (Parshall et al. 2009). For example in Ghana only 27% of rural households have access to electricity (GSS 2008). However, extending the grid in these countries faces significant technical constraints (e.g. insufficient grid generation capacity, geographic barriers to grid extensions, etc); and economic constraints (e.g. the economics of supply for sparsely populated and remotely located settlements given Government Budget restrictions). Hence, in the short to medium term the only realistic path is to extend the grid to only a subset of currently un-electrified rural settlements. For the remainder of settlements, many see decentralised systems and particularly those using renewable energy such as solar, wind, etc as being enormously important. Indeed, the evidence on the optimal balance between grid extension and off-grid solutions using renewable resources suggests that these latter could and should play an important role in access to electricity for SSA particularly where the price of such systems is continuing to fall (Deichmann et al, 2011). For example, recent research on Ghana shows that small household systems consisting of a solar panel PV plus battery would provide a cost effective solution to extending universal electrification for at least a million households (Abdul-Salam and Phimister, 2013).

While useful, such planning exercises presuppose adoption by households who are currently off-grid is straightforward. However, while grid extension is funded by central government, improving standalone access to electricity requires purchase and adoption of a capital intensive system by many poor (typically agricultural) households. However, as is well known poor agricultural households in LDCs typically face high levels of uncertainty as well as range of other market imperfections in credit, product and other markets which may impact negatively on their ability to invest (Fafchamps, 2003, Ray, 1998). Indeed Martinot et al (2001) argue that the slow rate of adoption of renewable energy technology in SSA countries is in part due to risk, transactions costs not observable in market prices and access to credit difficulties.

The aim of this paper is to explore the potential value of access to electricity for poor agricultural households and the extent to which credit and output market imperfections may inhibit the uptake of stand-alone solar panels by these households. In order to explore these effects a life cycle farm household model has been constructed which allows for positive welfare effects of access to electricity arising from improved farm productivity effects. Simulations from the model provide some initial quantification of the likely effect of market imperfections (credit constraint and risk), on stand-alone solar power investment by agricultural households.

Farm Household Model

Problem Structure

The starting point for the exploration of the impact of access to electricity on farm household welfare is an infinite horizon model allowing for agricultural and home electricity production, restrictions on borrowing, and yield risk. The approach is consistent with many models of this type in the literature, e.g. Phimister (1996, 1993), Singh et al (1986).

Small standalone systems are inadequate for motorised power on the agricultural holding. However, access to power also allows access to ICT which reduces price search costs and improves coordination and managerial control. There is now a body of evidence which support the view that ICT facilitated by access to electricity can have significant positive impacts on profits for small producers such as fishermen and farmers. For example, Aker (2008) found in Niger that mobile phones have an impact on price dispersion particularly where travel costs are high, while Overa (2006) showed evidence in Ghana of mobile phones helping reduce farmer's costs and increasing effectiveness of trade networks. Muto and Yamano (2008) found that mobile phone use in Uganda enabled higher market participation by small rural farmers producing perishable crops, while de Silva and Ratnadiwakara (2008) show that mobile phones significantly helped gherkin farmers in Sri Lanka reduce waste. Similarly Jensen (2007) found that the adoption of mobile phones decreased price dispersion and wastage by enabling the spread of information for Kerari fishermen in India, which made markets more efficient and enhanced both consumer and producer welfare.

To capture the income-enhancing potential effects of access to electricity on farm productivity, it is assumed here that the farm household's production is determined by a strictly concave function, $f(K, e)$ defined increasingly over capital (K) and electricity used in farm production (e). The transmission mechanism for increasing $f(.)$ due to (e) is the improved access to ICT and its accompanying channels for increased productivity. In addition, to capture the impact of access to electricity (used interchangeably with access to ICT) on farm income-uncertainty, we assume that probability distribution of the shocks to agricultural production $\varepsilon(D)$ is a function of the level of solar PV capital stock present on the farm D. This effect is specified by decreasing the variance of $\varepsilon(D)$ for higher stocks of

panel capital D. We assume that shocks impact on production in a multiplicative way as follows $\varepsilon.f(K,e)$. The production function for electricity $g(D)$ is naturally a function of the stock of solar capital D. The household's endogenously determined allocation of electricity for farm production (e) and for off-farm sale (s) is constrained by this function. At first glance allowing for sales of electricity for a household which is off-grid appears contradictory. However, evidence suggests that limited local markets for electricity services from off-grid electricity generation exist. For example, Barua (2010) describes case studies where rural households have invested in solar PV system and sold power to neighbours.

The problem can be naturally formulated as an infinite horizon dynamic programming problem, with three state variables capturing the household liquid asset level A, its level of solar capital stock D, and the shock to agricultural production ε. The decision problem is equivalent to an optimal replacement problem where the household wishes to maximize expected utility over a time additive utility function with a strictly concave subutility function, $u(.)$, defined over general consumption (C) for each period. Credit market imperfections are captured in the model by restricting possible asset values A' to the set of non-negative real numbers i.e. $A \in R^+$.

At the beginning of each period, the household must decide on how much of its available liquid asset A to spend on general consumption C and whether to invest in a new solar panel (b) or wait/postpone investment (i). The household period-beginning decision set C,b,i is constrained by the its period-beginning liquid asset A so that a decision set (C,b) is constrained by $A \geq C + p_d D_{new}$ whereas a decision set (C,i) is constrained by $A \geq C$. If the household invests (b), its available stock of panel capital for the current period immediately updates to $D = D_{new}$. The new panel D_{new} generates current period electricity production $g(D_{new})$ which is used in farm production (e) and off-farm sale (s). On the other hand, if the household decides to postpone investment in the current period (i), only the period-beginning stock of panel capital D would be available for use within the period. We allow for depreciation in our model so that the transition equations for stock of panel capital are $D' = (1-\delta)*D_{new}$ and $D' = (1-\delta)*D$ respectively for an investment decision (b) and a decision to postpone (i).

The household reaches a decision on b or i by comparing the maximum attainable utility from purchase $V^b(A,D,\varepsilon)$ with that from waiting $V^i(A,D,\varepsilon)$. The full model can be written as follows;

$$V(A, D, \varepsilon) = \max\left(V^b(A, D, \varepsilon), V^i(A, D, \varepsilon)\right) \tag{1}$$

where $V / V^b / V^i$ are the overall value function, the value function associated with panel purchase and the value function associated with not purchasing (i.e. inaction) respectively. A decision to purchase a new panel decomposes the household's optimisation problem into the following value function and transition equations;

$$V^b(A, D, \varepsilon) = \max_{C, s, e}\left\{u(C) + \beta E_{\varepsilon'|D'}V(A', D', \varepsilon')\right\}$$
$$A' = (1 + r) * (A - C - p_d D_{new}) + p_y.\varepsilon.f(\bar{K}, e) + p_s s$$
$$D' = (1 - \delta) * D_{new} \tag{2}$$
$$g(D_{new}) = e + s$$
$$A \geq C + p_D D_{new}$$

where the general consumption price is normalized to one, with p_y, p_s, p_d, defined as prices for output, electricity, and Solar PV investment respectively, while r is the exogenous interest rate. We assume in the above formulation that farm capital $\bar{K}$ is fixed.

If the household decides to postpone investment in the current period, its value function and transition equations are defined as follows;

$$V^i(A, D, \varepsilon) = \max_{C, s, e}\left\{u(C) + \beta E_{\varepsilon'|D'}V(A', D', \varepsilon')\right\}$$
$$A' = (1 + r) * (A - C) + p_y.\varepsilon.f(\bar{K}, e) + p_s s$$
$$D' = (1 - \delta) * D \tag{3}$$
$$g(D) = e + s$$
$$A \geq C$$

Notice that a decision not to invest whilst relaxing the current budget constraint through decreased expenditure would however constrain the amount of electricity produced $g(.)$ and would also lead to a greater income uncertainty due to increased variance in the distribution of productivity shock for the next period $\varepsilon' | D'$.

Model Solution

Dynamic programming problems of this type generally do not have tractable closed form solutions. Hence a number of numerical techniques could be used to approximate the solutions of these problems, e.g. value function, policy function iteration, projection methods etc. As is well known any discrete infinite horizon dynamic programming problem may be formulated as a linear programme. Hence following Puterman (1994), we use approximate

linear programming (ALP) to solve the problem numerically. The ALP formulation for the model (1)-(3) is as follows;

$$\max \sum_t \sum_a u(C) * x(A, D, \varepsilon, C, b/i, e)$$

such that

$$\sum_a x(A', D', \varepsilon', C, b/i, e) - \beta \sum_t \sum_a p(A', D', \varepsilon' \mid A, D, \varepsilon, C, b/i, e) * x(A, D, \varepsilon, C, b/i, e) = \psi$$

$$x(A, D, \varepsilon, C, b/i, e) \geq 0 \quad \forall \ a \in A; \ t \forall T$$

$$x(A, D, \varepsilon, C, b, e) = 0 \quad \forall \ A < C + p_D D_{new} \tag{4}$$

$$x(A, D, \varepsilon, C, i, e) = 0 \quad \forall \ A < C$$

$$x(A, D, \varepsilon, C, b/i, e) = 0 \quad \forall \ e + s > g(D)$$

$$t \in \{A, D, \varepsilon\}$$

$$a \in \{C, b/i, e\}$$

$x(.)$ is the endogenously determined policy function such that $x(.) > 0$ implies action set a is optimal for a household in state state set t. $x(.)$ equates to zero for all infeasible or suboptimal state and action set combinations. The attraction of ALP arises from the ease of imposing constraints using $x(.)$ as above. ψ is an arbitrary positive constant and β is the discount rate. $p(.)$ is the transition probability matrix of moving from current period state set $\{A, D, \varepsilon\}$ to next period state set $\{A', D', \varepsilon'\}$ given that action set $C, b/i, e$ is taken in the current period. In our model, the transition matrix $p(.)$ is controlled by the probability distribution of the shock factor $\varepsilon(D)$.

Model Initialisation

In the current version the model has been initialized using "reasonable" values plus parameter estimates from the wider literature. By definition this implies that the results obtained are at this stage only indicative. The state and action spaces in the model are initialised as follows;

Table 1:Base Model Initialisation

State and Action spaces	Grid size	Range of values
A	60	0.1 – 3.0
D	20	0.0 – 1.0
ε	5	0.0, 0.5, 1.0, 1.5, 2.0
$p_{|D=0}$		0.2,0.2,0.2,0.2,0.2
$p_{|D>0}$		0.1,0.2,0.4,0.2,0.1
C	40	0.1 – 3.0
i/b	2	0,1
ℓ	10	0.0 – 1.0

Table 1 above shows how risk is captured in our model via the state space ε. The shock to farm production ranges from 0.0 implying a full loss in all farm income to 2.0 implying a doubling of the household farm income relative to the average.

By definition the grid approximations mean that state and action spaces are restricted to a limited set of values. The size of the grids determines the degree of approximation in the model solution. The larger the grid, the more accurate the solutions obtained. There is however a trade-off between large grids, model dimensions and computer resource demand due to the curse of dimensionality. For example, with a problem of N state variables with each state variable discretised into n_s grid points, the value function has to be evaluated by N^{n_s} points (Adda and Cooper, 2003). Thus the problem size increases exponentially in grid points.[1]   Given the coarseness of the action grid, C, b/i and ℓ, the optimal policy functions which result are likely to be non-smooth. Finally, the following model parameters were initialised as follows;

Table 2: Benchmark parameters for model

Parameter	Function	Benchmark value
Risk aversion, η	CRRA Utility function, $u(.)$	2.00
Output elasticity of capital α	CRS Cobb-Douglas Production function, $f(.)$	0.60
Rate of time preference, ρ	…	0.15
Rate of depreciation, δ	…	0.05
Interest rate, r	…	0.10
Farm capital, K	$f(.)$	1.00
Available new panel size	…	1.00

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[1] For the above grid sizes, our model takes up 4GB of a quad-core computer memory and takes an hour and half to run.

Results

The solution to the dynamic programme (1.1-1.3) provides a set of optimal policy functions for consumption, investment and allocation of electricity in farm production. These policy functions are defined for all possible values of household liquid asset A, solar PV capital stock D and productivity shock ε. We are most interested in the optimal consumption function $C^* = h_1(A, D, \varepsilon)$ and investment function $I^* = h_2(A, D, \varepsilon)$. Investigating the nature of these functions provides insights into the potential impact of market imperfections (i.e. lack of access to credit) and risk on solar PV adoption decisions.

As a base comparator Figure 1 shows the optimal consumption policies of the farm household for all points on the liquid asset state-grid and for given points on the stock of panel capital state-grid when there is no uncertainty ($\varepsilon = 1.00$ in all states) in the farm production process. It is useful to concentrate on the extreme values of solar panel capital, i.e. when the household owns a new panel (panel capital equals one) or when the household does not own a panel (panel capital equals zero). When the household has a new panel (as shown in the upper line) the household consumes all its current assets (cash) when current assets are less than or equal to approximately 1.0. This is represented by the 45 degree line up to this point. In contrast, when the panel capital is zero, household consumption equals current assets (cash) up to around 0.25. This result is as expected; the higher the available stock of panel capital the household owns, the greater its future income generation possibilities hence its willingness to exhaust more of its assets in lower cash states. Beyond the 45-degree line and further along the cash axis, the household saves a portion of current assets. The act of saving is represented in the figure by the fact that consumption is lower than the 45-degree line. A household with no panel capital therefore starts saving at lower cash states (just above $A = 0.25$) than a household with high panel capital (just above $A = 1.0$). As there is no uncertainty in this version of the model, savings in this context is only for purposes of purchasing (or replacing) a solar panel. The propensity to save at much lower current asset/cash levels for households with no panel capital reflects their desire to accumulate savings for panel investment while attaining reasonable amounts of current consumption. Somewhat puzzlingly, the household consumption policy away from the 45 degree line is not monotonic but spiky. Whilst the downward spikes for example may represent actual decreases in consumption for savings or investment, they may also in part be explained by the constraints imposed implicitly by the fact that the solution is restricted to a grid of discrete values. At higher current asset levels for both cases we observe consumption markedly rising. This observation is more prominent for the case where the household has no stock of panel capital at all. To understand this effect better, we need to generate the household's associated savings and investment functions for this case.
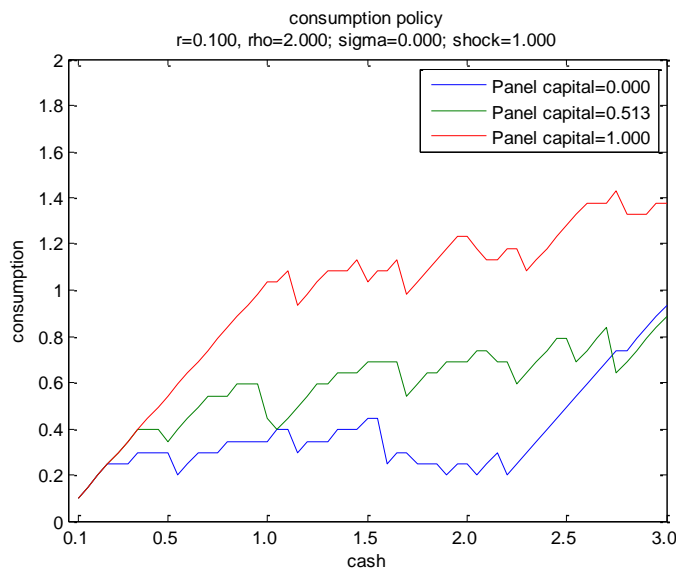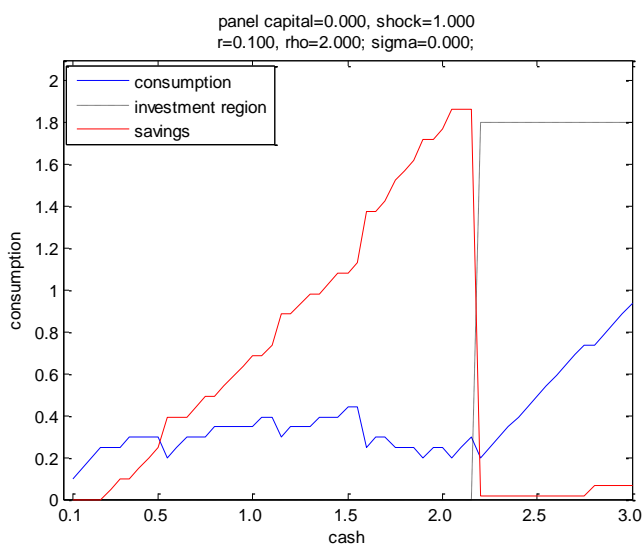
Figure 1 Optimal Consumption No Risk

Figure 2 below shows the consumption function, plus associated investment and savings functions for a household with no stock of panel capital. Notice that investment is only made at sufficiently large levels of current assets/cash. The reason for the sudden and significant increase in consumption as mentioned above is more apparent in this Figure. When the household has sufficiently high current assets/cash it makes an investment in a new panel. Figure 3 is a 3D investment function of the household showing the optimal invest/postpone decision for all possible combinations of liquid asset A and stock of liquid capital D. It shows that the maximum level of panel capital at which the household is willing to replace is about $D = 0.58$.

Figure 2: Consumption, Savings and Investment functions for Households without Solar PV
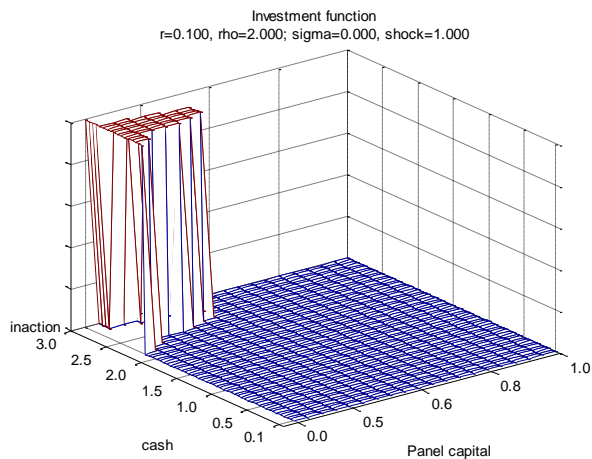
Figure 3: Solar Panel Investment Region – No Risk

Investment function
r=0.100, rho=2.000; sigma=0.000, shock=1.000

inaction
3.0
2.5
2.0
1.5
1.0
0.5
0.1
cash
1.0
0.8
0.6
0.5
0.0
Panel capital

Figure 4 shows the impact of different shocks to the analysis. For a household with no stock of panel capital D, the propensity to invest in a new panel at the beginning of a farming period is significantly affected by the size of the shock ε observed for that period. If the period beginning observed shock is sufficiently low, the household's propensity for investment is significantly higher than when the observed period beginning shock is high. In panel 1 of Figure 4 where the observed shock is unfavourable $(\varepsilon = 0.0)$, the household invests in a new panel when cash of up to about 2.1 is available. In the third panel where observed shock is highly favourable however $(\varepsilon = 2.0)$, the household is only willing to invest in a new panel if cash available at the beginning of the farming period is markedly higher at about 2.7.

Indeed, generally is a tendency to consume more in high shock periods rather than save or invest. These observations are consistent with fact that household has rational expectations about future shocks and therefore consider positive and negative shocks as transitory, although the probability of future shocks is conditions by the level the household panel capital D through the distribution $\varepsilon(D)$.
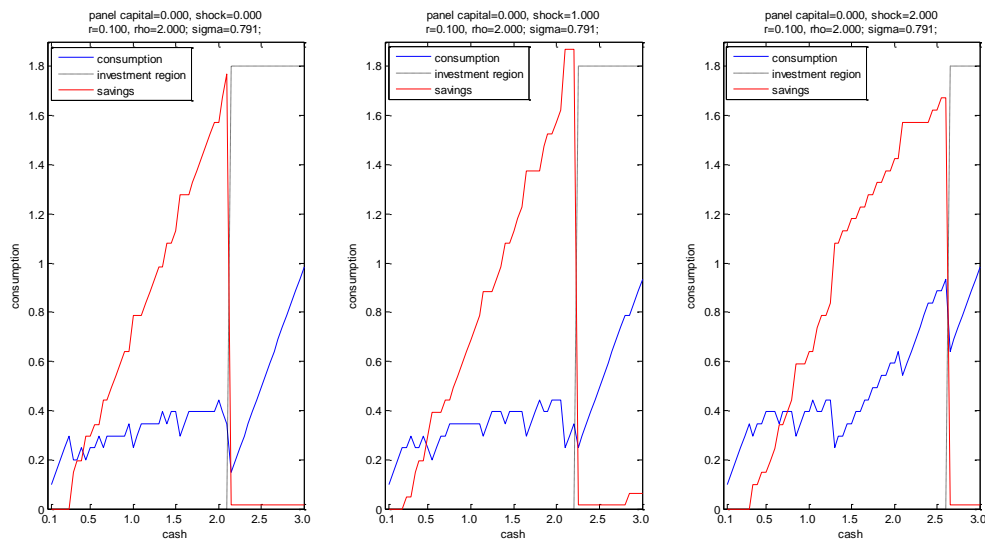
Figure 4 Impact of Risk on Investment Region

Figure 5 captures in 3D the investment function of the household for all possible combinations of liquid asset A, stock of durable capital D and select shock values ε. The effect of risk on the household propensity to invest is revealed in this figure. As was discussed above, the threshold for investment takes place at higher cash levels for high shock periods than for low shock periods. Interestingly however, Figure 5 also reveals a different aspect to the conditions for investment relative to the household's stock of panel capital. It is observed that in high shock regimes, households are more willing to replace panels of higher stock value than in low shock regimes. For example, in panel 1 (low shock regime), the maximum stock of panel capital the household would replace is about $D = 0.6$. In contrast, the maximum level of panel stock the household is willing to replace in panel 3 (high shock regime) is much higher i.e. about $D = 0.7$.

Figure 5: Effect of Risk on Investment Region
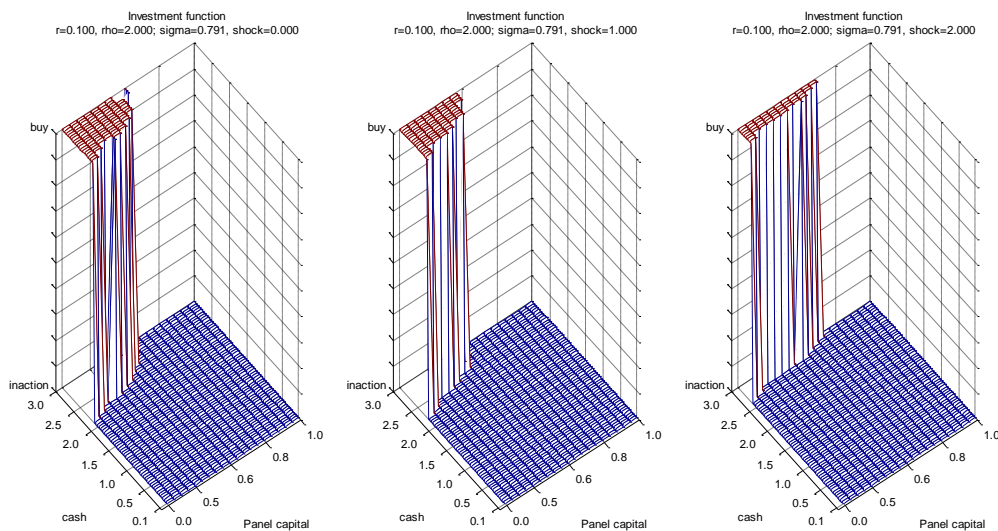
The implications of uncertainty on household consumption, investment and savings as discussed above may also be analysed using simulations. Whilst policy functions might be identical for some combinations of states, simulations may reveal not so obvious household behaviour. To do this we use the optimal policy functions to simulate household behaviour under a 70-period simulation for a poor farm household (initial conditions = low cash and no stock of panel capital) in a risky environment. The results of this analysis are shown in Figure 6.

Figure 6: Simulated Farm Household Consumption, Investment and Savings Behaviour
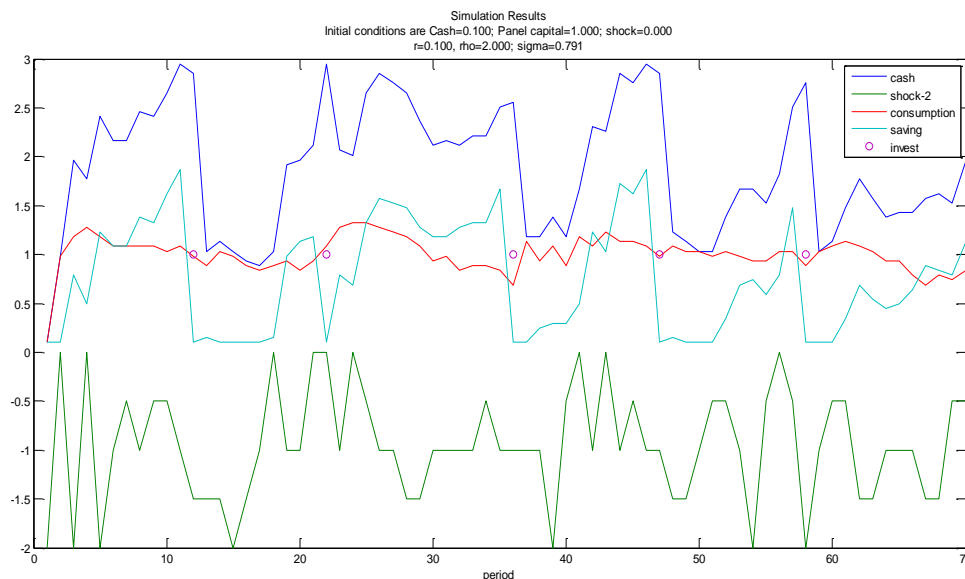
The bottom line show the set of shocks which were used in the simulation. As one would expect these shocks are reflected in savings and cash holdings, while consumption is significantly smoother, although still showing some variability. Also indicated are the points at which the farm household invests in the solar panel. Significantly although this happens on average around every 10 years, the interval between investments is not constant. Not unexpectedly the rate of savings in the period just before an investment is very high indeed, while the rate of saving in the period after an investment is markedly smaller, which perhaps captures how the lack of access to credit distorts savigns and consumption in these periods.

Summary and Conclusions

This paper has explored the potential value of access to electricity for agricultural households and the extent to which credit and output market imperfections may inhibit the uptake of stand-alone solar panels by farm households. In order to explore these effects a life cycle farm household model was constructed which allows for positive welfare effects of access to electricity arising from improved farm productivity effects. Simulations from the model provide some initial quantification of the likely effect of market imperfections (credit constraint and risk), risk aversion and interest rate on stand-alone solar power investment by agricultural households and the associated household welfare effects. They show the

potentially large impacts which both access to credit and risk have in the optimal decision of poor farm households (not) to invest in solar PV.

While illustrative of the trade-offs the model implemented has little empirical content. Improving this aspect is the focus of future work.

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