MONASH University
Business and Economics

DEPARTMENT OF ECONOMICS

ISSN 1441-5429

DISCUSSION PAPER 23/07

EXPLORING THE DETERMINANTS OF GLOBAL 'SOCIAL PRODUCTION' OF INFORMATION AND KNOWLEDGE: INSIGHTS FROM SETI@HOME

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Abstract

Commons-based peer production is an activity that is emerging as a distinct mode of resource allocation and production of information, knowledge and culture ('*social production*' for short), potentially heralding a new stage in the development of information/knowledge-based economies. This paper presents a cross-country analysis of factors determining the information and knowledge output of the paradigmatic *social production* project, i.e. SETI@home. The main hypothesis explored is that the level of average subjective well-being in a country is a motivational proxy variable that can help explain the cross-country variation in SETI@home output levels. The hypothesis that trust might be of lesser importance is also explored. I find support for both hypotheses, but only for developed and advanced countries, not poor countries.

Running Title: "Determinants of social production of information and knowledge"

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I. Introduction

SETI@home uses the idle capacity of millions of computers to search for signs of extraterrestrial intelligence in radio signals from space. Data units are distributed from the project's server via the Internet to participating computers that have downloaded the software to process them. Once processed, the output is returned and another data unit is downloaded. In this way, data are processed into information and knowledge, i.e. candidate signals are selected for further analysis. For some of its existence, SETI@home has been the most powerful special purpose supercomputer in the world.[1]

Benkler (2002, 2004, 2006) has argued that projects like SETI@home herald the rise of a so far mostly neglected mode of resource allocation and production of information, knowledge and culture in the digital age, i.e. commons-based peer production or '*social production*', whose salience in the economy is sensitive to technological conditions, although it is not solely determined by them.[2] S*ocial production* projects employ a varying mix of material resources (for example computing power and bandwidth) and non-material resources (for example efforts of creative labour) to create output. Projects include open source software, Wikipedia, Slashdot, the Open Directory Project, and Google. However, the roots of *social production* go back to the pre-Internet era, with car pooling being a prominent earlier example.

Benkler does not argue that *social production* will necessarily supplant other modes of production, or that it will always be the more efficient way of producing digital goods and services. Rather, it is a distinct mode that has some systematic advantages in identifying and allocating spare resources of human capital, creativity, and materials for the production of information, knowledge and culture. Should societies manage to keep open access to information and communication infrastructure and to existing information, knowledge and culture, *social production* might become more than a peripheral phenomenon and herald a new stage in the development of information/knowledge-based economies which goes beyond the currently dominant proprietary-based versions. Benkler calls this new stage the networked information economy.

The realisation of Benkler's vision will depend on whether an institutional framework and policies that support, or at least not hinder, *social production* can be put in place and successfully defended against competing interests of incumbent commercial producers and other threats. The stakes for economic progress are potentially very high if it is true that optimising the institutional system for price-based production undermines *social production,* and if it is true that current technological changes are improving the efficiency of *social production*. In that case, Benkler (2004, p. 281) argues that "we are making systematically mistaken policy choices not on the peripheries of our economies and societies, but at their very engines."

Benkler's hypotheses are interesting and controversial. They deserve further theoretical and empirical analysis. This paper and Engelbrecht (forthcoming) aim to contribute to the emerging research agenda by focussing on the analysis of one of the major examples of *social production* repeatedly used by Benkler, i.e. SETI@home. It has to be left to future research to determine to what extent the findings reported in this paper apply to *social production* in general.

Engelbrecht (forthcoming) shows that SETI@home participation and output per capita across 172 countries are not idiosyncratic but can be largely explained by the cross-country variation in Information and Communications Technology (ICT) access and use, GDP per capita (*gdp*), and region-specific effects. I included the largest number of countries possible, which enabled me to comment on the global SETI@home digital divide. However, this severely limited the availability of other explanatory variables, which are only available for much smaller samples of countries.

The current paper incorporates variables related to the motivation for participating in SETI@home, reducing my sample to just over 60 countries. In particular, I propose to link *social production* to happiness economics, a branch of economics that has expanded rapidly in recent years. Insight from happiness economics are becoming more mainstream and are likely to increasingly influence public policy in future.[3] The main hypothesis tested in this paper is that happiness, as commonly measured by subjective well-being (*SWB*), is a motivational proxy variable that can help explain the cross-country variation in

SETI@home output levels. Moreover, I explore the relative explanatory power of trust versus *SWB*. Trust is a major component of social capital and has been shown to have positive impacts on economic activity (see, for example, Knack and Keefer, 1997). Benkler (2004), however, has argued that social capital might not be a prerequisite for *social production*, which mostly involves only very weakly connected communities or even total strangers.

My major findings are that there is indeed statistically significant evidence of a positive correlation between the level of *SWB* in a country and *social production* in terms of SETI@home, but only for the group of rich countries, and that stronger results are obtained for the *SWB* variable compared to the trust variable. However, given the current constraints on data availability and the simple model that could be tested, these findings can only be interpreted as suggestive. It is hoped they will stimulate further research.

Section II provides some information on SETI@home and addresses the vexed question of why people might participate in such an activity. Variable selection and data sources are discussed in Section III. This is followed by the empirical analysis (Section IV), which reports correlations and some exploratory regressions. Section V contains concluding comments.

II. Why Participate in SETI@home?

SETI@home was launched in May 1999. By December 2004 it had more than 5 million participants ('users'), who made resources available to the project (computing power and bandwidth). Benkler (2004) comments that distributed computing projects like SETI@home look like cases of mass altruism among strangers. Some information on the profile of SETI@home users and their professed reasons for participating in the project can be gained from a continuous on-line poll available on the SETI@home website. By 30 March 2005 approximately 140,000 people had participated in the poll. When asked for the main reason why they were participating in the project 58.5% said they did it 'for the good of humanity', followed by about 17% responding 'to keep my computer busy'. Only about 3% admitted to participating in order 'to become famous', and even fewer said they participated in order to get their name listed on the SETI@home website. Although one has to be careful not to read too much into them, these responses provide a broad picture of what motivates SETI@home users to participate in the project.

Benkler (2002, 2004) discusses in some detail the diverse motivations of contributors to public resource computing projects. Apart from altruistic and reputational considerations, human beings like to be creative and participate in creative acts. SETI@home also fulfils the desire on part of many amateur scientists to be involved in a science project.[4] The design of the client interface and the SETI@home website in general try to provide the type of incentives and feedback that binds participants to the project by providing meaning to their

contribution (they include a screen saver, user and results data, certificates, scientific information etc.).

The voluntary nature of participation links SETI@home to the extensive economics literature on altruism, gifting and volunteering. Economists usually agree that seemingly altruistic behaviour is often a mixture of different motivations, both altruistic and egotistic.[5] Fehr and Fischbacher (2002) argue that economists fail to understand even core issues of their discipline if they insist on egotistic preferences at the exclusion of social preferences like reciprocal fairness, inequity aversion and pure altruism. Altman (2005) argues that a broader neoclassical framework is especially appropriate and feasible when the consequences of economic agents' choices are not answerable to market forces. In that case neoclassical theory stresses the opportunity costs of non-egotistic behaviour. Moreover, Altman sees an inverse relationship between the quantity of virtuous acts undertaken and the level of opportunity costs. In the case of SETI@home, the opportunity costs are likely to be low, facilitating high levels of participation.

I conclude that participation in SETI@home and in similar projects cannot be explained by assuming standard egotistic utility maximising behaviour. Instead, I hypothesize that, ceteris paribus, happier people might be more altruistic and therefore more likely to participate in *social production*. More precisely, I hypothesize that the degree of voluntary participation in SETI@home, and therefore output produced, is correlated with the average level of *SWB* in society.

SWB can also be interpreted as a proxy variable for motivational factors linked to important features of a society's value system (see the discussion in Section III).

Benkler (2004) explicitly discusses the relationship between *social production* and the literature on social norms and social capital or trust. There are similarities in that both emphasise social relations, but they differ in that the latter are usually thought of as enabling market exchange and production, whereas *social production* refers to a different mode of production. Benkler (2004, p. 333/334) argues that *social production*

> "… is a broader phenomenon, one that includes cooperate enterprises that can be pursued by weakly connected participants or even by total strangers and yet function as a sustainable and substantial modality of economic production. Indeed, in the context of the digitally networked environment, it is this type of sharing and cooperative production among strangers and weakly connected participants that holds the greatest economic promise."

Whether the networks of strangers or of weakly connected participants characterising *social production* still qualify as social capital is a moot question that could be debated at length. Dasgupta (2005), for example, defines social capital as interpersonal networks, in contrast to impersonal markets. The social relations underlying *social production* in the case of SETI@home seem to fit somewhere in between these two. However, it should be remembered that trust is

one of the factors explaining *SWB*. Therefore, even if it is not directly correlated with participation in *social production* projects, it might be indirectly via *SWB*.[6]

III. Variable Selection and Data Sources

Variable selection was guided by insights obtained from the literature on ICT/Internet diffusion and use. This literature reports a diversity of findings with regard to statistically significant explanatory variables. A few studies are briefly discussed to highlight this point. Kiiski and Pohjola (2002) investigate the determinants of Internet diffusion across a sample of OECD countries during 1995-2000. They find that *gdp* and Internet access costs are the best explanatory variables for the growth of computer hosts per capita. Competition in telecommunication markets does not seem to have an independent influence. Education only becomes statistically significant in a larger sample of both industrial and developing countries.

Using a panel of 161 countries over the 1999-2001 period, Chinn and Fairlie (2004) confirm the importance of income differentials in explaining the gap in computer and Internet use found in many other studies, but they also report that it is not always the only major factor. For example, differences in telecommunication infrastructure can be a rival factor. Secondly, in their country sample telecommunication access prices (and other policy factors) are swamped by economic, demographic and institutional factors. Thirdly, they find that the

quality of regulation is of great importance. Furthermore, education co-varies with Internet use, but the education effect is small (i.e. in many cases accounting for only half of the effect attributable to differences in regulatory quality).

In contrast to the above, Caselli and Coleman II (2001), in their study of computer diffusion from 1970 to 1990 for a sample of up to 90 countries, find that human capital (i.e. high levels of educational attainment) is an important determinant of computer technology adoption, even after controlling for other variables including *gdp*. Similarly, Pohjola (2003), in a study of ICT adoption and diffusion of 49 developed and developing countries during the 1993-2000 period, finds that human capital, the relative price of computers, and the level of income, are the most important determinants of computer use.

Taking account of these and other findings, and considering the limited number of observations available for this study, I focus on just three types of variables that are assumed to be correlated with the cross-country variation in SETI@home participation as measured by processed data units (i.e. outputs). First, there are the motivational proxy variables used to explore my hypotheses about the importance of *SWB* and trust. Secondly, there is a variable that captures Internet availability and its various dimensions, including infrastructure, abilities of users (i.e. human capital), cost of access, the general level of use. Thirdly, there is a variable that accounts for the material standard of living in general. Variable definitions and data sources are discussed below. The data are available from the discussion paper version of this paper (Engelbrecht, 2006).

SETI@home variables (SETI, ΔSETI)

Data on SETI@home output (i.e. number of data units processed) per capita were obtained from the SETI@home classic website. They take into account all processed data units submitted since the beginning of the project. Because of this cumulative nature of the data, I not only use 10 December 2002 output per capita (*SETI*), but also the *change* in output per capita from 10 December 2002 to 13 December 2004 (*ΔSETI*). Both variables are actual outcomes-based measures of Internet use. They measure participation not simply in terms of number of participants or period of participation, but in terms of its intensity (i.e. outcomes). There are large cross-country differences in SETI@home output per capita. The top ranked countries are Finland in December 2002 (1.86) and Iceland in December 2004 (4.18). The lowest ranked country in both years is Nigeria (0.00004 in December 2002, 0.00014 in December 2004).

Motivational proxy variables (SWB, Trust)

Since the 1940s happiness or life satisfaction surveys have been accumulating steadily, and they have been a goldmine of data mostly for social scientists other than economists (Easterlin, 2002). However, in recent years there has been a proliferation of happiness research in economics. The consensus seems to be that the average level of happiness in a country is linked to and can be explained by objective factors. For example, Layard (2005) cites research that suggests that just

six factors can explain 80% of the cross-country variation in happiness as reported in the World Values Survey (WVS). They are the divorce rate, unemployment rate, level of trust, membership in non-religious organisations, quality of government, fraction of the population believing in God. Layard argues that happiness is supremely important because it is the main motivational device of the human species.

The happiness variable used in this paper, i.e. *SWB*, is based on the 1999-2002 wave of the WVS (Inglehart et al. 2004). It is constructed from the responses to two questions, i.e. from the percentages of people who reported "feeling very happy" and "being satisfied with life" (see ibid., Tables A008, A170).[7] *SWB* is a remembered utility measure. Such measures have already been reported in the literature to be relevant for some subsequent choices.[8]

Inglehart (2005) reports a positive link between *SWB* and economic development. This relationship is non-linear, with *SWB* seemingly levelling off for rich countries. Starting with Easterlin (1974), this has been observed by numerous happiness researchers.[9] Inglehart (2005) views *SWB* as a good proxy for the extent of *self-expression values,* which themselves proxy for post-material values associated with affluent societies. Poorer countries, by contrast, are characterised by *survival values*. Therefore, the WVS not only highlights cross-cultural variation in people's beliefs and values but also indicates that value systems of rich countries differ dramatically and systematically from those of poor countries. However, there are some interesting anomalies. Most Latin American countries

have higher *SWB* levels than suggested by their level of economic development, whereas the opposite applies to ex-Soviet countries. In my data sample, *SWB* ranges from -1.81 for the Ukraine to 4.32 for Mexico.

I also experimented with an alternative, but less-up-to-date, happiness variable taken from the World Database of Happiness (WDH) (variable hlt_90s)(Veenhoven, 2005). It reports mean happiness scores for the 1990s for each country. It is the overall happiness variable in the WDH with the largest number of observations. However, as might be expected, it has lower correlations with the SETI@home variables, suggesting that the more up-to-date variable *SWB* is preferable. For details, see Engelbrecht (2006).

Benkler's view that social capital might not be important for participation in *social production* suggests that there might be little correlation between (*Δ)SETI* and *Trust*. Inglehart et al. (2004) report, however, that societies that rank high on self-expression values also rank high on interpersonal trust, i.e. *SWB* and *Trust* might be highly correlated. The large literature on social capital reports quite diverse findings, partly due to the complexity of the concept and the fact that as yet there is no strong theory of social capital formation at the aggregate level.[10]

To explore the relationship between *SWB* and social capital, I include a trust variable (*Trust*) derived from the WVS as an alternative motivational variable. It is the percentage of people who thought that "most people can be trusted" (see ibid., Table A165). In my data set, values for *Trust* range from a low of 0.03 for

Brazil to a high of 0.67 for Denmark. Beugelsdijk (2006) argues that in macro-level studies, and particularly in the context of poorer countries, *Trust* is better considered a proxy for well-functioning institutions rather than for social capital. This is another important hint that not only the size of correlations between my variables, but also their interpretation, might differ systematically between rich and poor countries.

Other variables (DAI, gdp)

The other two variables included in the analysis are the *Digital Access Index (DAI)* and *gdp*, both for 2002. The ITU (2003) argues that access to ICTs is a most fundamental requisite for an inclusive information society, and that new indicators are needed that go beyond those measuring ICT infrastructure. To remedy the shortcomings of existing indices it introduced the *DAI*. This is a composite index attempting to capture a mix of demand and supply conditions of ICTs. It is made up of eight sub-indices: Number of fixed telephone and mobile telephone subscribers, Internet access price, adult literary rate, school enrolment rate, number of broadband subscribers, international Internet bandwidth, number of Internet users. They are first aggregated into five sub-components before being aggregated into one index (see Appendix Table A1). The *DAI*'s value ranges between 0 and 1. In my data sample, Sweden has the highest *DAI* (0.85), Nigeria the lowest (0.15). However, comparisons are most valuable for similar countries (ibid., p. 99). This again raises doubts about the inclusion of both rich and poor countries in the same data sample.

Last but not least I include *gdp* in purchasing power parity adjusted US$ reported in UNDP (2004) as a measure of material living standards. Numerous studies analysing ICT/Internet diffusion and use have included it as a key explanatory variable. *gdp* varies widely in my data sample, i.e. between US$ 61,190 for Luxembourg and US$ 860 for Nigeria.

IV. Empirical Analysis

The empirical analysis consists of two parts. I first analyse correlations between the variables. Secondly, I report some exploratory regressions.

Correlations

Table 1A reports correlations in the data sample that includes both rich and poor countries.[11] Using the Fisher z-test, all correlations are found to be statistically significant at the 1% level and most of them are quite high. *DAI* and *gdp* have higher correlations with the SETI@home variables than do *SWB* and *Trust*. As far as correlations amongst non-SETI@home variables are concerned, they are highest between *gdp* and *DAI*, and lowest between the *SWB* and *Trust*. Correlations between the motivational proxy variables and *gdp* are quite high. Also note that the correlation between *Trust* and *(Δ)SETI* is higher than that

between *SWB* and *(Δ)SETI*. These correlations do not lend support to the hypothesis that *Trust* might be less important than *SWB* in explaining *(Δ)SETI*.

[put Table 1 about here]

However, my earlier discussion indicated that many of the relationships between variables are likely to differ between the groups of rich and poor countries, i.e. the correlations reported in Table 1A may be grossly misleading. A plot of *SETI* against *SWB* also indicated that the relationship between these two variables is not straightforward: A number of observations lie along the *SWB* axis (see Engelbrecht, 2006). The data suggest this is due to the 'Latin American effect' mentioned earlier. I therefore also report separate correlations for the group of 'developed and advanced' (i.e. rich) countries versus 'the rest' (the poor). The definition of the former group is taken from ITU (2003, p. xi) and includes 26 countries in my sample.[12] The remaining 36 countries comprise 'the rest' (see Engelbrecht, 2006, for details). The poorest country in the developed and advanced country group is the Republic of Korea (*gdp* of US$ 16,950 in 2002). In December 2004, the developed and advanced countries accounted for 20.3% of the population of the 63 country sample, but 89.7% of all SETI@home users and 91.6% of all processed data units.

In the developed and advanced country sample the motivational proxy variables become relatively more important (see Table 1B). The highest correlations between *(Δ)SETI* and other variables are those involving *SWB*. A plot of *SETI*

against *SWB* suggested a clearly positive relationship. There is no evidence of a levelling off at higher levels of *SWB* (see Engelbrecht, 2006). *Trust* has the second highest correlation with *SETI* (and the third highest with *ΔSETI)*. In contrast to the 62 country sample, correlations between *(Δ)SETI* and *DAI*, as well as *(Δ)SETI* and *gdp*, are lower (and statistically insignificant in the case of *gdp*). Amongst the non-SETI@home variables, only *SWB* is positively correlated with *gdp* at the 1% level. The correlations between *gdp* and *Trust*, and *gdp* and *DAI*, are greatly reduced compared to Table 1A, and they are no longer statistically significant. To sum up, in developed and advanced countries the *social production* of information and knowledge in the SETI@home case is highly correlated with *SWB*, and to a lesser extend with *Trust* and *DAI*, but not with *gdp*.

A very different picture emerges from the correlation matrix for the sample of other countries (Table 1C). For this group, *gdp* and *DAI* are highly correlated with *(Δ)SETI*, whereas all correlations involving the motivational proxy variables are small and statistically insignificant. Tables 1A, 1B, 1C suggest that the groups of rich and poor countries should be analysed separately. For the former group, motivational proxy variables, as well as *DAI*, are highly correlated with *social production* in the SETI@home case, whereas for the latter group, the non-motivational variables seem to be of overwhelming importance. This suggests that Inglehart's *self-expression values* might be a prerequisite for *social production.* It also highlights the importance of non-technical obstacles against establishing *social production* in today's poorer countries, and the importance of defending

self-expression values from erosion in rich countries, if *social production* is to have any chance of becoming more than a peripheral phenomenon.

Some exploratory regressions

The model proposed to put some causal structure on the relationships between variables is very simple and of an exploratory nature only. It is assumed that *(Δ)SETI* is explained by *DAI*, *gdp* and a variable that proxies for the main motivational factors for this type of *social production* activity (alternatively using *SWB* and *Trust*). The estimated equations are of the following general form:

$$\begin{Bmatrix} SETI_i \\ \Delta SETI_i \end{Bmatrix} = \alpha_0 + \alpha_1 DAI_i + \alpha_2 gdp_i + \alpha_3 \begin{Bmatrix} SWB_i \\ Trust_i \end{Bmatrix} + \varepsilon_i \qquad (1)$$

where i indexes countries and ε is a white noise error term. Applying the extended Box-Cox transformation, each variable is transformed in the same way according to $x = \left(x^{\lambda} - 1\right)/\lambda$, where x is a variable and λ is the transformation parameter. If λ = 1, equation (1) is linear, if λ = 0, it is logarithmic. Other values of λ correspond to more complicated functional forms. I do not focus on particular functional forms, but on the general properties of the regressions as expressed in the reported test statistics and, for economic interpretation, the elasticities implied by the regression estimates.[13]

In most happiness research using regression analysis *SWB* is the dependent variable, i.e. the focus is on the determinants of *SWB*.[14] Only a few studies seem to have explored the possibility of happiness causing economic outcomes. Kenny (1999) investigates the hypothesis that happiness causes economic growth for a sample of OECD countries and finds weak support for it (and no support for the causal link running from economic growth to happiness). Graham et al. (2004) use panel data from Russia to assess whether happiness affects income, health, and other factors. They find that the level of 'residual happiness' left after controlling for the degree of happiness associated with its usual determinants has a positive impact on people's future earnings and health. However, there is also evidence that volunteer and charity work is often a source of happiness (Frey and Stutzer, 2002). One might speculate that this applies equally to participation in *social production* projects. Unfortunately, I do not (yet) have suitable data available to properly explore the issue of reverse causality between the dependent and explanatory variables. Furthermore, it is also possible that there are interaction effects between the various explanatory variables, especially between *gdp* and others.[15]

Regression results for the data sample that includes both groups of countries are reported in Table 2. In all cases λ is either zero or close to it, indicating that the estimated equations are logarithmic. The elasticities at the mean are, therefore, quite similar to the reported coefficient estimates. DW tests for serial correlation of the residuals and general misspecification of the model. The null hypothesis is accepted at the 1% level of significance for all regressions except (2.4), for which

the DW statistic is inconclusive. JB is a test for normality of the residuals and also for general model misspecification. The JB values indicate that the null hypothesis is accepted at the 1% level of significance in all cases.

[put Table 2 about here]

Only elasticities for statistically significant estimates are shown at the bottom of Table 2. *DAI* is the most elastic. On average, if *DAI* is increased by 1%, *SETI* increases by almost 3% and *ΔSETI* by almost 4%. Although the explanatory power of all regressions is high (see the adjusted R^2 values), the motivational proxy variables perform badly, either being statistically insignificant or being statistically significant and negative! Inclusion of a country group dummy variable for 'developed and advanced countries' in the regressions did not improve the estimates.

Next, I estimate the model separately for the two groups of countries. Regressions for 'the rest' do not improve the estimates for the motivational proxy variables. They are, therefore, not reported. Those for developed and advanced countries are shown in Table 3. Focussing on this small group of 26 countries makes it even more important to keep the model as simple as possible in order to preserve degrees of freedom.

[put Table 3 about here]

The regressions reported in Table 3 provide quite a different picture from those reported in Table 2, echoing the differences observed in the correlation analysis. On the one hand, *gdp* and *DAI* are only statistically significant in about half of the regressions (and in none of the *ΔSETI* regressions). On the other hand, parameter estimates for the motivational proxy variables all have positive signs and they are all statistically significant, with *SWB* having a higher level of significance than *Trust*. Differences also emerge with respect to the overall explanatory power of regressions. Those including *SWB* have appreciably higher explanatory powers than those including *Trust*, and those for *SETI* have higher explanatory power than those for *ΔSETI*. Moreover, regressions including *SWB* are the only ones for which the null hypothesis of the DW test is accepted. The JB values seem to suggest that all reported regressions have normally distributed residuals. However, the JB test is known not to perform well for small data samples.

The elasticities for the statistically significant estimates indicate that *DAI* still has the highest elasticity at the mean, but that *SWB* is now also highly elastic. The impacts of *Trust* and *gdp* on *(Δ)SETI* are inelastic. The estimates reported in Table 3 seem to support the hypotheses that *SWB* captures some major determinants of the cross-country variation in *(Δ)SETI*, and that *Trust* is of lesser importance.

V. Concluding Comments

The findings reported in this paper suggest that links between the literatures on happiness economics and *social production* are worth exploring further. The correlation and regression analyses found that in rich countries, *SWB* and *Trust*, which I assume to proxy for motivational factors, are important determinants of output levels in the *social production* project SETI@home, as are factors captured by *DAI*. Furthermore, there is some limited support for the hypothesis that *Trust* might be a weaker (possibly less direct) explanatory variable.

It is worth repeating that the reported results cannot be regarded as conclusive, leaving ample scope for further research. In particular, the available data greatly limited the extent to which causal relationships could be modelled. There is the issue of potential reverse causality between *(Δ)SETI* and the other variables, as well as potentially important interactions between the other variables themselves. Also, when a composite index like *DAI* is used, cross-country variation in the variables underlying the index is lost. The *DAI's* sub-indices are likely to be better suited to highlight areas that might need policy attention, i.e. the research should be extended by separately modelling the major components of the *DAI*. Sceptical readers will also want to explore the importance of alternative happiness and social capital variables. Another obvious extension would be to assemble a micro-level data set, i.e. to use observations on individuals, in order to test whether the correlations observed in the macro data can be confirmed at the micro level. Similar studies should be conduced for other *social production* projects. Only then will we know whether SETI@home is representative of *social production* in general.

[put the Appendix table here]

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Table 1. Correlation coefficients

1A) 62 observations data set (all p < 0.01)

SETI	1.000					
ΔSETI	0.938	1.000				
DAI	0.728	0.718	1.000			
gdp	0.751	0.712	0.839	1.000		
SWB	0.560	0.476	0.545	0.619	1.000	
Trust	0.702	0.572	0.482	0.514	0.355	1.000
	SETI	ΔSETI	DAI	gdp	SWB	Trust

1B) 26 observations data set (developed and advanced countries)

SETI	1.000					
ΔSETI	0.960*	1.000				
DAI	0.681*	0.603*	1.000			
gdp	0.404	0.447	0.226	1.000		
SWB	0.755*	0.712*	0.439	0.548*	1.000	
Trust	0.721*	0.592*	0.650*	0.169	0.507*	1.000
	SETI	ΔSETI	DAI	gdp	SWB	Trust

* = p < 0.01

1C) 36 observations data set (other countries, 'the rest')

SETI	1.000					
ΔSETI	0.938*	1.000				
DAI	0.674*	0.618*	1.000			
gdp	0.772*	0.671*	0.912*	1.000		
SWB	0.016	-0.015	0.113	0.197	1.000	
Trust	-0.001	0.007	-0.173	-0.139	-0.220	1.000
	SETI	ΔSETI	DAI	gdp	SWB	Trust

* = p < 0.01

Table 2. Explaining cross-country variation in (Δ)SETI, large data set

	(2.1)	(2.2)	(2.3)	(2.4)
Dep. Variable:	*SETI*	*SETI*	*ΔSETI*	*ΔSETI*
Indep. Variables:				
DAI	2.877[a] (3.164)	2.760[a] (3.350)	3.706[a] (3.796)	3.804[a] (4.097)
gdp	1.299[a] (3.470)	0.948[a] (3.232)	1.484[a] (3.189)	0.922[b] (2.407)
SWB	-0.093 (-1.105)		-0.212[b] (-2.290)	
Trust		0.183 (0.804)		0.010 (0.042)
Intercept	-3.830[a] (-2.766)	-2.902[b] (-2.171)	-3.100[c] (-1.966)	-2.062 (-1.305)
No. ob obs.	62	63	62	63
Adj. R^2	0.860	0.853	0.868	0.848
DW	2.085	2.135	2.352	2.495
JB (2DF)	2.944	3.005	8.749	2.674
λ	0.020	0.05	-0.030	0.00
Elasticities at mean:				
DAI	2.900	2.815	3.702	3.804
gdp	1.399	1.141	1.343	0.922
SWB	-		-0.376	
Trust		-		-

[a] Denotes $p < 0.01$. [b] Denotes $0.01 < p < 0.05$. [c] Denotes $0.05 < p < 0.10$. All regressions are estimated using the extended Box-Cox model. In regressions (2.1) and (2.3) SWB is not transformed because some observations are negative. t-ratios are given in brackets. DW is the Durbin-Watson d test statistic. JB is the Jarque-Bera test statistic. Its critical value at the 1% level of significance is $\chi^2_{(2)} = 9.21$.

Table 3. Explaining cross-country variation in (Δ)SETI, developed and advanced countries.

	(3.1)	(3.2)	(3.3)	(3.4)	(3.5)	(3.6)	(3.7)	(3.8)
Dep. Variable:	*SETI*	*SETI*	*SETI*	*SETI*	*ΔSETI*	*ΔSETI*	*ΔSETI*	*ΔSETI*
Indep. Variables:								
DAI	3.320[b] (2.444)	3.323[b] (2.392)	3.801[c] (1.914)	3.095 (1.625)	2.830 (1.695)	2.853 (1.676)	3.978 (1.542)	2.955 (1.232)
gdp		-0.007 (-0.061)		0.058[b] (2.184)		0.035 (0.403)		0.089[b] (2.291)
SWB	1.124[a] (6.338)	1.132[a] (5.017)			0.938[a] (4.861)	0.866[a] (3.629)		
Trust			1.558[b] (2.644)	1.406[b] (2.636)			1.316[c] (1.780)	1.156[c] (1.770)
Intercept	-0.971[c] (-1.869)	-0.937 (-1.227)	1.793[a] (4.457)	0.733 (1.213)	-0.672 (-1.082)	-0.858 (-1.045)	1.915[a] (3.649)	0.434 (0.551)
Adj. R^2	0.734	0.722	0.527	0.580	0.606	0.590	0.355	0.448
DW	2.102	2.100	0.821	1.058	1.785	1.785	0.860	1.121
JB (2DF)	0.062	0.065	1.701	0.534	0.308	0.223	0.386	0.075
λ	0.130	0.370	0.790	0.720	0.470	0.480	0.740	0.680
Elasticities at mean:								
DAI	3.234	3.240	3.603	-	-	-	-	-
gdp		-		0.744		-		0.842
SWB	1.835	1.849			1.558	1.455		
Trust			0.861	0.819			0.630	0.588

[a] Denotes $p < 0.01$. [b] Denotes $0.01 < p < 0.05$. [c] Denotes $0.05 < p < 0.10$.
All regressions are based on 26 observations per variable. Also see notes to Table 2.

Appendix:

Table A1. Components of the Digtal Access Index (DAI), 2002

Indicator	**Goal-post**	**Sub-Components (in italics) and their composition**
Fixed telephone subscribers per 100 inhabitants[1]	60	Each has a one half weight for *infrastructure*, which proxies for overall ICT network development.
Mobile subscribers per 100 inhabitants	100	
Adult literacy[2]	100	Literacy has a two-third weight and enrolment a one-third weight for *knowledge*, which affects a country's ability to use new technologies.
Overall school enrolment (primary, secondary and tertiary)[2]	100	
Internet access price (20 hours per month) as percent of monthly per capita income[3]	1	This is subtracted from 1 to form an indicator that proxies *affordability* of Internet access. (1=free Internet)
Broadband subscribers per 100 inhabitants[4]	30	Each has a one half weight for *quality* of access to ICTs.
International Internet bandwidth per capita	10'000	
Internet users per 100 inhabitants	85	A proxy for Internet *usage*.

Notes: 1. Public Switched Telephone Network (PSTN) plus Integrated Services Digital Network (ISDN) subscribers. 2. Obtained from the UNDP's Human Development Index. 3. Cheapest dial-up or broadband plan averaged over 20 hours of peak and 20 hours of off-peak usage. Annual average exchange rates from the IMF are used to convert the Internet tariffs into US dollars. GNI per capita data are from the World Bank. 4. Including Digtal Subcriber Line (DSL), cable modem and other technologies faster than 128 kbit/s in at least one direction.
Source: ITU (2003, Table 5.1, p. 106, Table 5.2, p. 108).

Endnotes

[1] For a history of the SETI@home project and of the science behind it see Anderson et al. (2002) and http://seticlassic.ssl.berkeley.edu/. All SETI@home information used in this paper refers to what is now known as the 'SETI@home classic' project which finished in early 2006.

[2] Benkler observes that technology imposes threshold constraints on *social production*, but that it cannot unilaterally determine its level, which is also influenced by cultural practices and tastes.

[3] The literature on happiness-related policy discussions is expanding fast. See, for example, Layard (2005), Helliwell (2006) and Frey and Stutzer (2007).

[4] It has a relative advantage over science projects requiring collaboration based on more formal organisational and institutional structures ('e-science') which make it a lot more difficult to overcome transaction costs (David, 2006).

[5] See, for example, Fehr and Fischbacher (2003) and Bénabou and Tirole (2005). Altman (2005) and Katz and Rosenberg (2005) provide reviews of the literature.

[6] There is some evidence that social capital might be a variable explaining *SWB* (see Bjørnskov, 2003; Helliwell., 2006), but issues of mutual causality loom large.

[7] Inglehart (2005, p. 11) explains the construction of *SWB* as follows: "Happiness was rated on a four-point scale, on which high scores indicated low levels of happiness; life satisfaction was rated on a ten point scale on which high scores indicated high levels of satisfaction. To give both variables equal weight, the mean scores on the happiness scale were multiplied by 2.5 and subtracted from the life satisfaction scores."

[8] For recent surveys of the advantages and disadvantages of remembered utility measures and their uses in economics see, for example, Kahneman and Krueger (2006) and Di Tella and MacCulloch (2006).

[9] However, there is also some support for the rival view that there is a robust positive relationship between income levels and happiness in rich countries (Di Tella et al., 2003; Hagerty and Veenhoven, 2003; Oswald, 2005).

[10] For comprehensive and critical surveys of social capital research see, for example, Durlauf and Fafchamps (2005) and Dasgupta (2005).

[11] For Malta *SWB* was not available, reducing the data set from 63 to 62 countries.

[12] They are Iceland, Finland, Denmark, Canada, Netherlands, US, Sweden, UK, New Zealand, Luxembourg, Australia, Germany, Norway, Austria, Switzerland, Belgium, Ireland, Portugal, France, Spain, Singapore, Greece, Israel, Italy, Japan, Rep. of Korea.

[13] The only exception to transforming all variables by the same λ occurs when the data sample includes poor countries. In that case, some of the observations for *SWB* are negative. Therefore, the Box-Cox transformation breaks down and *SWB* is not transformed.

[14] See, for example, the survey by Di Tella and MacCulloch (2006).

[15] Adding interacted variables to equation (1) did not improve the regression estimates, due to the small sample size and multicollinearity problems.