**Supplementary Material** for “Linking Entrepreneurship to Productivity: Developing a Composite Indicator for Farm-Level Innovation in UK Agriculture with Secondary Data”

**Supplementary Material**

**Non-parametric Data Envelopment Analysis (DEA)**

**The set of inputs and outputs in a production system**

A farm is considered as a Decision-Making Unit (DMU) that decides over the selection of the production plan (i.e. the set of inputs to produce a set of outputs). Consequently, the farm serves as the system that transforms inputs into outputs.

To formalise the above let us assume that we observe a set of farms and each farm has a set of inputs and outputs representing multiple performance measures. For the farm then the of inputs and the of outputs are defined as and respectively[[1]](#footnote-1). The production plan for the farm is thus defined as a pair of input and output vectors:

Note that and it is therefore presumed that both inputs and outputs for the farm are non-negative numbers i.e. they are positive or zero.

For a set of farms the input data matrix and the output data matrix can be arranged as follows:

In benchmarking theory, the basic assumption is that a set of DMUs have a common and homogenous underlying technology defined by the technology or production possibility set ,

The production possibility set (PPS) is denoted by the social, technical, mechanical, chemical and biological environment in which the production process takes place (Bogetoft & Otto, 2010). Conceptually the PPS is defined as the minimum technology that satisfies the assumptions of feasibility of the observed input and output combinations, that the PPS is convex, the free disposability of inputs and outputs and that If is feasible, then for any, is also feasible without specifying any functional form (Banker et al., 1984; Bogetoft & Otto, 2010).

**Estimating the MI of TFP**

According to Färe, Grosskopf, Norris, et al. (1994) the distance functions required for the calculation of the MI of TFP, i.e. ,

are computed with the use of DEA techniques. Specifically, four different linear programs must be solved. Suppose that for each period there is set of farms which use a set of inputs and outputs representing multiple performance measures. Considering then that each farm uses inputs, to produce outputs

The first Shephard input distance function is estimated as follows:

Where and are the of inputs and the of outputs defined as above as and respectively. Further, note that the notation has changed and that farms and input or outputs are indicated as subscripts. The value of is the technical efficiency for the farm. Also note that stands for the Shephard distance function and for the Farrell distance function. The second input distance function is estimated as follows:

The third input distance function required for the MI of TFP , considers data from the period relative to technology based on data from period . Specifically,

Finally, the third input distance function required for the MI of TFP , considers data from period relative to technology based on data from period . Specifically

Note that each distance function must be calculated for each farm in each period.

**Statistical inference for MI of TFP and their components**

Despite the significant advantages of DEA for the calculation of the MI of TFP we need to consider the fact that the estimates of productivity may be affected by sampling variation. In other words, it is possible to underestimate the distance functions to the frontier if the best performing farms in the population are excluded from the sample since DEA is a Benchmarking technique and it only considers the farms in the sample (Kelvin Balcombe et al., 2008; Simar & Wilson, 1999). To overcome this shortcoming Simar & Wilson (2000) and Simar & Wilson (2007) proposed a bootstrapping method for the construction of confidence intervals for the DEA efficiency estimates relying on smoothing the empirical distribution. The rationale behind bootstrapping is to simulate the true sampling distribution by mimicking the data generation process (DGP) (K. Balcombe et al., 2008). Through the DGP a pseudo-data set is constructed which is then used for the re-estimation of the DEA distance functions. Increasing the bootstrapped replicates (more than 2000. See Simar & Wilson, (1998b) allows for a good approximation of the true distribution of the sample.

Simar and Wilson (1999) adapted the bootstrapped procedure for the estimation of the MI of TFP in order to account for possible temporal correlation arising from the panel data characteristics (Kelvin Balcombe et al., 2008). Specifically, they proposed a consistent method using a bivariate kernel density estimate that accounts for the temporal correlation via the covariance matrix of data from adjustment years. The bootstrapped estimates of the distance functions allow the calculation of a set of MI of TFP which accounts for the bias and enables the estimation of confidence intervals. The latter are used for statistical inference of the MI of the TFP and its components.

**Supplementary tables**

**Table S1. Statistical inference of the MI of TFP over the 11 periods for cereal farms**

| Farm ID | 2003/2004 | 2004/2005 | 2005/2006 | 2006/2007 | 2007/2008 | 2008/2009 | 2009/2010 | 2010/2011 | 2011/2012 | 2012/2013 | 2013/2014 |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| 1 | 1.203\*\*\* | 0.814\*\*\* | 0.607\*\*\* | 0.832\*\*\* | 1.195\*\*\* | 0.898\*\*\* | 0.818\*\*\* | 1.257\*\*\* | 1.163\*\*\* | 0.896\*\*\* | 0.750\*\*\* |
| 2 | 0.715\*\*\* | 0.840\*\*\* | 0.992 | 1.040 | 0.990 | 0.766\*\*\* | 1.208\*\*\* | 0.973 | 0.948 | 0.955 | 1.484\*\*\* |
| 3 | 1.214\*\*\* | 0.879\*\*\* | 0.830\*\*\* | 0.794\*\*\* | 1.089\*\* | 1.014 | 0.885\*\*\* | 1.064 | 1.270\*\*\* | 0.988 | 1.164 |
| 4 | 0.928\*\* | 1.056\*\* | 0.856\*\*\* | 0.742\*\*\* | 0.811\*\*\* | 1.343\*\*\* | 0.729\*\*\* | 0.927\*\*\* | 1.254\*\*\* | 1.371\*\*\* | 0.926\*\*\* |
| 5 | 1.243\*\*\* | 0.954\*\* | 0.869\*\*\* | 0.807\*\*\* | 0.878\*\*\* | 1.284\*\*\* | 0.777\*\*\* | 0.974 | 1.297\*\*\* | 0.681\*\*\* | 1.755\*\*\* |
| 6 | 1.448\*\*\* | 0.833\*\*\* | 0.979 | 0.674\*\*\* | 1.018 | 1.026 | 0.686\*\*\* | 1.013 | 1.115\*\*\* | 0.849\*\*\* | 1.190\*\*\* |
| 7 | 0.843\*\*\* | 0.879\*\*\* | 1.011 | 0.884\*\*\* | 0.816\*\*\* | 0.999 | 0.796\*\*\* | 0.847\*\*\* | 2.331\*\*\* | 0.717\*\*\* | 0.804\*\*\* |
| 8 | 1.101\*\*\* | 0.924\*\*\* | 0.819\*\*\* | 0.611\*\*\* | 1.230\*\*\* | 1.657\*\*\* | 0.578\*\*\* | 0.792\*\*\* | 1.501\*\*\* | 1.091\*\*\* | 0.959 |
| 9 | 1.186\*\*\* | 0.630\*\*\* | 1.345\*\*\* | 0.909\*\*\* | 0.858\*\*\* | 1.292\*\*\* | 0.657\*\*\* | 1.135\*\*\* | 1.483\*\*\* | 0.660\*\*\* | 0.912\*\*\* |
| 10 | 1.148\*\*\* | 0.551\*\*\* | 1.113\*\*\* | 1.298\*\*\* | 0.773\*\*\* | 0.857\*\*\* | 1.006 | 0.777\*\*\* | 1.581\*\*\* | 1.392\*\*\* | 0.886\*\*\* |
| 11 | 1.460\*\*\* | 0.769\*\*\* | 1.090\*\* | 0.775\*\*\* | 0.816\*\*\* | 1.554\*\*\* | 0.737\*\*\* | 0.886\*\*\* | 1.180\*\*\* | 0.987 | 1.256\*\*\* |
| 12 | 1.145\*\*\* | 0.848\*\*\* | 0.893\*\*\* | 0.670\*\*\* | 0.871\*\*\* | 1.805\*\*\* | 0.688\*\*\* | 0.886\*\*\* | 1.346\*\*\* | 1.300\*\*\* | 1.169\*\*\* |
| 13 | 0.774\*\*\* | 0.728\*\*\* | 0.761\*\*\* | 0.876\*\*\* | 1.390\*\*\* | 1.132\*\*\* | 1.064 | 0.703\*\*\* | 1.109\*\* | 1.139\*\*\* | 0.545\*\*\* |
| 14 | 1.416\*\*\* | 1.069 | 0.788\*\*\* | 0.903\*\* | 0.685\*\*\* | 2.072\*\*\* | 0.906\*\*\* | 1.079\*\*\* | 0.814\*\*\* | 0.849\*\*\* | 1.231\*\*\* |
| 15 | 1.091\*\*\* | 0.928\*\*\* | 0.927\*\*\* | 0.622\*\*\* | 1.344\*\*\* | 1.178\*\*\* | 0.638\*\*\* | 0.862\*\*\* | 1.330\*\*\* | 1.161\*\*\* | 0.871\*\* |
| 16 | 1.196\*\*\* | 1.066\*\*\* | 0.909\*\*\* | 0.792\*\*\* | 0.882\*\*\* | 0.962 | 0.738\*\*\* | 0.819\*\*\* | 1.329\*\*\* | 1.193\*\*\* | 0.974 |
| 17 | 1.427\*\*\* | 0.949\*\*\* | 0.781\*\*\* | 0.647\*\*\* | 0.880\*\*\* | 1.283\*\*\* | 0.726\*\*\* | 0.902\*\*\* | 1.141\*\*\* | 1.017 | 1.203\*\*\* |
| 18 | 1.163\*\*\* | 0.912\*\* | 0.730\*\*\* | 0.799\*\*\* | 0.888\*\*\* | 1.303\*\*\* | 0.909\*\*\* | 0.911 | 1.082\*\* | 1.209\*\*\* | 1.128 |
| 19 | 1.267\*\*\* | 0.990 | 0.820\*\*\* | 0.724\*\*\* | 1.234\*\*\* | 1.059 | 0.889\*\*\* | 0.740\*\*\* | 1.209\*\*\* | 1.589\*\*\* | 1.098\*\*\* |
| 20 | 1.094\*\*\* | 0.818\*\*\* | 0.966\*\*\* | 0.870\*\*\* | 0.795\*\*\* | 1.111\*\*\* | 0.976 | 0.808\*\*\* | 1.324\*\*\* | 0.750\*\*\* | 1.307\*\*\* |
| 21 | 1.177\*\*\* | 0.586\*\*\* | 1.130 | 0.992 | 0.571\*\*\* | 1.846\*\*\* | 0.552\*\*\* | 0.650\*\*\* | 2.371\*\*\* | 1.187 | 1.199 |
| 22 | 1.228\*\*\* | 0.817\*\*\* | 0.898\*\*\* | 0.729\*\*\* | 0.768\*\*\* | 1.738\*\*\* | 0.621\*\*\* | 0.929\*\*\* | 1.425\*\*\* | 0.981 | 1.094\*\*\* |
| 23 | 1.000 | 0.310\*\*\* | 1.891\*\*\* | 0.539\*\*\* | 1.332\*\*\* | 1.698\*\*\* | 0.771\*\*\* | 0.722\*\*\* | 1.029 | 1.788\*\*\* | 0.768\*\*\* |
| 24 | 1.329\*\*\* | 0.978 | 0.885\*\*\* | 0.775\*\*\* | 0.672\*\*\* | 1.758\*\*\* | 0.616\*\*\* | 1.020 | 1.565\*\*\* | 1.047 | 1.037 |
| 25 | 1.289\*\*\* | 0.824\*\*\* | 0.926 | 0.810\*\*\* | 0.470\*\*\* | 1.919\*\*\* | 0.902\*\* | 0.808\*\*\* | 1.722\*\*\* | 0.813\*\*\* | 0.974 |
| 26 | 1.208\*\*\* | 1.018\*\* | 0.601\*\*\* | 0.938\*\* | 1.463\*\*\* | 0.837\*\*\* | 0.920 | 1.573\*\*\* | 1.981\*\*\* | 0.538\*\*\* | 0.827\*\*\* |
| 27 | 1.179\*\*\* | 0.950\*\*\* | 1.013 | 0.629\*\*\* | 0.959 | 1.590\*\*\* | 0.625\*\*\* | 0.919\*\*\* | 1.312\*\*\* | 1.174\*\*\* | 1.099\*\*\* |
| 28 | 0.921 | 0.988 | 0.829\*\*\* | 0.698\*\*\* | 1.221\*\*\* | 1.477\*\*\* | 0.661\*\*\* | 1.069\*\*\* | 0.970 | 0.909 | 1.775\*\*\* |
| 29 | 0.945 | 1.063 | 0.750\*\*\* | 1.433\*\*\* | 0.875 | 1.721\*\*\* | 0.892\*\*\* | 0.910\*\*\* | 0.858\*\*\* | 1.086\*\*\* | 1.141\*\*\* |
| 30 | 0.730\*\*\* | 0.953 | 0.836\*\*\* | 0.875\*\*\* | 0.884\*\*\* | 1.276\*\*\* | 0.810\*\*\* | 0.690\*\*\* | 2.096\*\*\* | 0.847\*\*\* | 1.195\*\*\* |
| 31 | 1.201\*\* | 0.614\*\*\* | 0.714\*\*\* | 1.142\*\*\* | 1.728\*\*\* | 0.543\*\*\* | 1.107 | 0.886\*\* | 1.099\*\*\* | 1.110\*\*\* | 2.036\*\*\* |
| 32 | 1.162 | 0.797\*\*\* | 0.839\*\*\* | 0.785\*\*\* | 1.430\*\*\* | 0.836\*\* | 1.182\*\*\* | 0.774\*\*\* | 1.602\*\*\* | 0.942\*\* | 1.147\*\*\* |
| 33 | 1.184\*\*\* | 0.536\*\*\* | 1.548\*\*\* | 0.371\*\*\* | 1.556\*\*\* | 1.087\*\*\* | 0.409\*\*\* | 1.154\*\*\* | 1.606\*\*\* | 0.912 | 1.185\*\*\* |
| 34 | 1.519\*\*\* | 1.278\*\*\* | 0.781\*\*\* | 0.573\*\*\* | 0.672\*\*\* | 1.904\*\*\* | 0.815\*\*\* | 0.885\*\*\* | 0.778 | 1.220\*\*\* | 1.186\*\*\* |
| 35 | 1.072\*\*\* | 0.965 | 1.095\*\*\* | 0.779\*\*\* | 0.473\*\*\* | 1.991\*\*\* | 0.847\*\*\* | 1.092\*\*\* | 0.781 | 1.154\*\*\* | 0.919\*\*\* |
| 36 | 0.993 | 0.943\*\*\* | 0.776\*\*\* | 0.818\*\*\* | 0.721\*\*\* | 1.431\*\*\* | 0.713\*\*\* | 1.309\*\*\* | 1.045 | 1.261\*\*\* | 1.095\*\*\* |
| 37 | 0.815\*\*\* | 1.533\*\*\* | 0.640\*\*\* | 1.110 | 0.884\*\*\* | 1.228\*\*\* | 0.659\*\*\* | 0.723\*\*\* | 1.564\*\*\* | 0.791\*\*\* | 1.174\*\*\* |
| 38 | 1.128 | 0.845\*\*\* | 0.953\*\* | 0.743\*\*\* | 1.317\*\*\* | 1.105 | 0.375\*\*\* | 1.504\*\*\* | 1.625\*\*\* | 0.812\*\*\* | 0.971 |
| 39 | 1.252\*\*\* | 0.848\*\*\* | 0.981 | 0.863\*\*\* | 0.603\*\*\* | 1.512\*\*\* | 0.756\*\*\* | 0.805\*\*\* | 1.031 | 1.206 | 1.147\*\*\* |
| 40 | 1.608\*\* | 0.816\*\*\* | 0.577\*\*\* | 1.686\*\*\* | 0.576\*\*\* | 1.304\*\*\* | 1.053\*\*\* | 0.647\*\*\* | 1.225\*\*\* | 1.195\*\*\* | 0.731\*\*\* |
| 41 | 1.139\*\*\* | 0.747\*\*\* | 1.005 | 0.871\*\*\* | 0.647\*\*\* | 1.961\*\*\* | 1.171\*\*\* | 0.900\*\* | 1.079\*\*\* | 1.174\*\*\* | 1.037 |
| 42 | 1.114\*\*\* | 0.677\*\*\* | 0.813\*\*\* | 1.059 | 1.059 | 1.410\*\*\* | 0.479\*\*\* | 1.445\*\*\* | 0.935 | 0.870\*\*\* | 1.245\*\*\* |
| 43 | 0.840 | 1.011 | 0.829\*\*\* | 0.775\*\*\* | 1.553\*\*\* | 0.788\*\*\* | 0.957 | 1.041 | 1.182\*\*\* | 1.031 | 0.950 |
| 44 | 0.871 | 1.044 | 0.952\*\* | 0.747\*\*\* | 1.166\*\*\* | 1.106\*\*\* | 0.689\*\*\* | 1.155\*\*\* | 0.793\*\*\* | 0.952\*\*\* | 1.105\*\*\* |
| 45 | 1.363\*\*\* | 0.798\*\*\* | 0.787\*\*\* | 0.624\*\*\* | 1.200\*\*\* | 1.213\*\*\* | 0.790\*\*\* | 0.862\*\*\* | 1.317\*\*\* | 1.330\*\*\* | 0.958\*\*\* |
| 46 | 1.197\*\* | 0.907\*\*\* | 0.897\*\*\* | 0.663\*\*\* | 1.155\*\*\* | 0.871\*\*\* | 1.157\*\* | 0.770\*\*\* | 1.287\*\*\* | 0.615\*\*\* | 1.731\*\*\* |
| 47 | 1.320\*\*\* | 0.856\*\*\* | 0.744\*\*\* | 0.954\*\* | 0.768\*\*\* | 1.324\*\*\* | 0.813\*\*\* | 0.816\*\*\* | 1.341\*\*\* | 1.224\*\*\* | 0.793\*\*\* |
| 48 | 0.920 | 0.817\*\*\* | 1.240\*\*\* | 1.314\*\*\* | 0.886\*\*\* | 1.009 | 0.823\*\*\* | 0.762\*\*\* | 1.102 | 1.519\*\*\* | 0.898\*\*\* |
| 49 | 1.294\*\*\* | 0.875\*\*\* | 0.966\*\* | 0.773\*\*\* | 0.869\*\*\* | 1.181\*\*\* | 0.875\*\*\* | 0.833\*\*\* | 1.220\*\*\* | 1.187\*\*\* | 0.958 |
| 50 | 1.110 | 1.048\*\*\* | 0.810\*\*\* | 0.700\*\*\* | 1.026 | 1.003 | 0.952 | 0.672\*\*\* | 1.426\*\*\* | 1.091\*\*\* | 1.132\*\*\* |
| 51 | 0.984 | 0.626\*\*\* | 1.013 | 1.070 | 0.910\*\*\* | 1.395\*\*\* | 0.725\*\*\* | 0.835\*\*\* | 1.362\*\*\* | 1.179\*\*\* | 0.844\*\*\* |
| 52 | 0.925\*\*\* | 0.987\*\* | 0.879\*\*\* | 0.549\*\*\* | 1.262\*\*\* | 0.915\*\* | 0.615\*\*\* | 1.747\*\*\* | 0.851\*\*\* | 0.932\*\* | 1.460\*\*\* |
| 53 | 0.770\*\*\* | 0.801\*\*\* | 1.250\*\* | 1.444\*\*\* | 0.846\*\* | 1.173\*\*\* | 0.862\*\*\* | 0.673\*\*\* | 1.261\*\*\* | 1.201\*\*\* | 0.927\*\*\* |
| 54 | 0.970 | 0.668\*\*\* | 0.730\*\*\* | 0.924\*\*\* | 1.228\*\*\* | 1.512\*\*\* | 0.481\*\*\* | 1.044 | 1.261\*\*\* | 1.545\*\*\* | 0.849\*\*\* |
| 55 | 1.082 | 0.782\*\*\* | 0.822\*\*\* | 0.810\*\*\* | 0.854\*\*\* | 1.335\*\*\* | 0.780\*\*\* | 0.914\*\*\* | 0.918\*\*\* | 1.402\*\*\* | 1.308\*\*\* |
| 56 | 1.084\*\*\* | 0.894\*\* | 0.738\*\*\* | 0.741\*\*\* | 0.919\*\*\* | 1.045 | 1.801\*\*\* | 0.587\*\*\* | 2.031\*\*\* | 0.643\*\*\* | 1.275\*\*\* |
| 57 | 0.736\*\*\* | 1.035 | 0.899\*\*\* | 0.695\*\*\* | 0.885 | 1.022 | 1.319\*\*\* | 0.612\*\*\* | 1.688\*\* | 0.929\*\*\* | 0.895\*\*\* |
| 58 | 0.849 | 1.072\*\*\* | 0.907\*\*\* | 0.728\*\*\* | 0.826\*\*\* | 1.708\*\*\* | 0.541\*\* | 0.932\*\*\* | 1.753\*\*\* | 0.673\*\*\* | 1.521\*\*\* |
| 59 | 1.198\*\*\* | 0.945\*\*\* | 0.925\*\*\* | 0.900\*\*\* | 0.825\*\*\* | 1.295\*\*\* | 0.725\*\*\* | 0.986 | 1.188\*\* | 0.987 | 1.080\*\* |
| 60 | 1.098\*\*\* | 0.846\*\*\* | 1.059\*\* | 0.766\*\*\* | 0.875\*\*\* | 1.095\*\*\* | 1.087\*\*\* | 0.735\*\*\* | 1.308\*\*\* | 0.974 | 1.150\*\*\* |

\*\* Significantly different from unity at 0.05 level

\*\*\* Significantly different from unity at 0.01 level

**Table S2. Detailed presentation of the pure efficiency change factor for each individual farm in the sample over the 11-year period**

| FARM ID | 2003/2004 | 2004/2005 | 2005/2006 | 2006/2007 | 2007/2008 | 2008/2009 | 2009/2010 | 2010/2011 | 2011/2012 | 2012/2013 | 2013/2014 |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| 1 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 |
| 2 | 0.65\*\*\* | 1.07 | 1.03 | 1.24\*\*\* | 0.76\*\*\* | 0.92 | 1.09 | 1.08 | 0.85\*\*\* | 1.17 | 1.27\*\*\* |
| 3 | 0.81\*\*\* | 0.97 | 1.05 | 1.00 | 0.87\*\*\* | 0.97 | 1.00 | 0.95 | 1.28\*\*\* | 1.00 | 0.94 |
| 4 | 0.81\*\*\* | 1.09\*\* | 1.08\*\* | 0.94 | 0.72\*\*\* | 1.27\*\*\* | 0.77\*\*\* | 1.11 | 0.95 | 1.34\*\*\* | 1.00 |
| 5 | 1.056 | 1.07 | 1.03 | 0.88\*\* | 0.74\*\*\* | 1.57\*\*\* | 0.88\*\* | 0.95 | 0.86\*\*\* | 0.96 | 1.44\*\*\* |
| 6 | 1.22\*\*\* | 1.08 | 1.11 | 0.85\*\*\* | 0.97 | 0.91 | 0.99 | 1.06 | 0.91 | 0.80\*\*\* | 1.18\*\*\* |
| 7 | 0.64\*\*\* | 1.55\*\*\* | 0.94 | 1.07 | 0.94 | 0.84\*\*\* | 1.05 | 0.90\*\* | 1.21\*\*\* | 0.94 | 0.88 |
| 8 | 1.13 | 1.03 | 0.93 | 0.92 | 1.27\*\*\* | 0.92 | 1.18\*\* | 0.77\*\*\* | 1.20\*\*\* | 0.88\*\* | 1.17\*\* |
| 9 | 1.00 | 1.00 | 1.32\*\*\* | 1.00 | 0.91 | 1.01 | 0.83\*\*\* | 1.16\*\*\* | 1.10\*\* | 0.87\*\* | 0.90 |
| 10 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 |
| 11 | 1.19\*\*\* | 0.85\*\*\* | 1.44\*\*\* | 0.90 | 0.82\*\*\* | 1.25\*\*\* | 0.98 | 0.94 | 0.99 | 0.86\*\*\* | 1.25\*\*\* |
| 12 | 0.91 | 1.29\*\*\* | 0.88 | 0.88 | 1.04 | 1.14\*\* | 0.93 | 1.00 | 0.97 | 1.21\*\*\* | 1.00 |
| 13 | 0.82\*\* | 1.00 | 1.00 | 1.00 | 1.09 | 0.92 | 1.16 | 0.86 | 1.00 | 1.00 | 1.00 |
| 14 | 1.00 | 1.03 | 0.97 | 1.00 | 1.00 | 1.00 | 1.02 | 1.05 | 0.93 | 1.00 | 1.00 |
| 15 | 0.84\*\*\* | 1.01 | 1.16\*\*\* | 0.84\*\*\* | 1.19\*\*\* | 1.25\*\*\* | 0.83\*\*\* | 0.84\*\*\* | 1.06 | 1.10\*\* | 0.66\*\*\* |
| 16 | 1.04 | 1.13\*\* | 0.95 | 1.13 | 0.98 | 0.77\*\*\* | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 |
| 17 | 1.15\*\*\* | 0.96 | 1.06 | 0.79\*\*\* | 1.03 | 1.06 | 1.08 | 0.83\*\* | 0.92 | 1.00 | 1.17\*\*\* |
| 18 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.08 | 0.93 | 1.00 | 1.00 | 1.18 |
| 19 | 1.00 | 1.12\*\* | 0.96 | 0.93 | 1.05 | 0.95 | 1.20\*\* | 0.84\*\* | 1.00 | 1.08 | 1.15\*\* |
| 20 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 |
| 21 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 |
| 22 | 0.93 | 0.86\*\*\* | 1.23\*\*\* | 0.88\*\* | 0.85\*\* | 1.17\*\* | 0.85 | 1.00 | 1.11 | 0.90 | 1.17 |
| 23 | 0.87\*\*\* | 0.92 | 1.28\*\* | 0.78\*\* | 1.10 | 1.39\*\*\* | 1.05 | 0.76\*\*\* | 0.83\*\*\* | 1.62\*\*\* | 0.66 |
| 24 | 1.41\*\*\* | 1.02 | 1.12 | 0.88 | 0.79\*\*\* | 1.26\*\*\* | 0.89 | 1.17\*\*\* | 1.16\*\*\* | 0.99 | 0.99 |
| 25 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 |
| 26 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.30\*\*\* | 0.77\*\*\* | 1.00 |
| 27 | 1.09 | 1.09 | 1.08 | 0.87\*\*\* | 0.99 | 1.08\*\* | 0.90 | 0.97 | 1.08 | 1.06 | 1.08 |
| 28 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 |
| 29 | 1.00 | 1.01 | 0.99 | 1.00 | 1.43\*\*\* | 1.08 | 0.95 | 0.97 | 0.98 | 1.16\*\* | 0.94 |
| 30 | 0.78\*\*\* | 1.05 | 0.96 | 1.14 | 1.05 | 0.84 | 1.00 | 1.00 | 1.20 | 0.83 | 1.09 |
| 31 | 1.05 | 0.95 | 1.00 | 1.01 | 1.23\*\*\* | 0.80\*\*\* | 1.00 | 1.00 | 1.00 | 1.09 | 1.22\*\* |
| 32 | 1.22 | 0.82 | 1.00 | 1.00 | 1.00 | 1.00 | 1.27\*\*\* | 0.79\*\* | 1.10 | 1.13 | 1.18\*\* |
| 33 | 0.76\*\*\* | 0.93 | 1.26\*\*\* | 0.79\*\*\* | 1.20 | 0.95 | 0.88 | 1.00 | 1.02 | 0.98 | 1.00 |
| 34 | 1.00 | 1.39\*\* | 0.72\*\*\* | 1.00 | 1.04 | 0.96 | 1.12 | 0.89 | 1.00 | 1.00 | 1.00 |
| 35 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 |
| 36 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.01 | 1.02 |
| 37 | 1.00 | 1.26\*\*\* | 0.79\*\*\* | 1.33\*\*\* | 0.88\*\*\* | 1.08 | 0.95 | 0.84\*\* | 1.11 | 0.90 | 1.21\*\* |
| 38 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 |
| 39 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 |
| 40 | 1.00 | 1.05 | 0.96 | 1.32\*\*\* | 0.83\*\*\* | 0.98 | 1.12 | 0.83\*\*\* | 1.09 | 1.21\*\*\* | 0.76\*\*\* |
| 41 | 1.16 | 0.86 | 1.01 | 1.27\*\* | 0.78\*\* | 1.00 | 1.11 | 1.27 | 0.87 | 1.03 | 1.04 |
| 42 | 0.93 | 0.97 | 0.92 | 1.12 | 1.03 | 1.20\*\*\* | 0.72\*\*\* | 1.42\*\*\* | 0.70\*\*\* | 1.00 | 1.25 |
| 43 | 0.96 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 |
| 44 | 0.83\*\*\* | 1.11\*\* | 1.17\*\* | 0.90 | 0.94 | 1.28\*\*\* | 0.89\*\* | 1.05 | 0.75\*\*\* | 0.97 | 1.26\*\* |
| 45 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 |
| 46 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 |
| 47 | 1.11\*\* | 0.97 | 0.99 | 1.16\*\* | 0.80\*\*\* | 1.19\*\*\* | 1.01 | 0.90\*\* | 1.18\*\*\* | 1.37\*\*\* | 0.68\*\*\* |
| 48 | 0.93 | 1.00 | 1.08 | 1.10 | 0.99 | 0.88 | 1.23\*\*\* | 0.78\*\*\* | 1.12 | 1.13 | 0.80\*\*\* |
| 49 | 1.01 | 1.08 | 1.11 | 0.95 | 0.88\*\* | 1.00 | 1.19 | 0.85\*\*\* | 0.99 | 1.12 | 1.04 |
| 50 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 |
| 51 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 |
| 52 | 0.84\*\*\* | 1.08 | 0.97 | 0.93 | 0.89\*\* | 1.00 | 0.94 | 1.07 | 0.93 | 1.13 | 1.08 |
| 53 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 |
| 54 | 0.77\*\*\* | 0.98 | 0.89 | 1.09 | 1.22\*\*\* | 1.39\*\*\* | 0.65\*\*\* | 1.08 | 0.92 | 1.10 | 0.95 |
| 55 | 1.00 | 1.00 | 1.00 | 1.00 | 1.02 | 0.98 | 1.04 | 0.96 | 1.00 | 1.00 | 1.00 |
| 56 | 1.05 | 1.16\*\*\* | 0.93 | 0.86\*\*\* | 0.82\*\*\* | 1.00 | 1.93\*\*\* | 0.72\*\*\* | 1.47\*\*\* | 0.66\*\*\* | 1.28\*\*\* |
| 57 | 0.61\*\*\* | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.71\*\*\* | 0.70\*\*\* | 1.18\*\*\* | 0.99 | 0.96 |
| 58 | 0.65\*\*\* | 1.49\*\*\* | 1.14\*\*\* | 0.82\*\*\* | 0.75\*\*\* | 1.61\*\*\* | 0.59\*\*\* | 1.08 | 1.34\*\*\* | 0.86 | 1.23\*\*\* |
| 59 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 |
| 60 | 0.87\*\*\* | 0.91\*\* | 1.19\*\*\* | 1.02 | 0.81\*\*\* | 1.00 | 1.00 | 1.00 | 1.04 | 1.16\*\*\* | 1.03 |

\*\* Significantly different from unity at 0.05 level

\*\*\* Significantly different from unity at 0.01 level

**Table S3. Detailed presentation of the scale efficiency change factor for each individual farm in the sample over the 11-year period**

| FARM\_ID | 2003/2004 | 2004/2005 | 205/2006 | 2006/2007 | 2007/2008 | 2008/2009 | 2009/2010 | 2010/2011 | 2011/2012 | 2012/2013 | 2013/2014 |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| 1 | 0.97 | 0.99 | 0.78\*\*\* | 1.06 | 1.31\*\* | 0.72\*\*\* | 1.00 | 1.26\*\*\* | 1.08 | 0.79 | 0.93 |
| 2 | 0.96 | 0.99 | 1.04 | 1.04 | 0.99 | 1.01 | 1.25 | 0.86 | 0.86\*\*\* | 1.01 | 1.23\*\* |
| 3 | 1.23\*\*\* | 0.93 | 0.96 | 1.01 | 0.99 | 1.17 | 0.79\*\* | 1.34\*\*\* | 0.71\*\*\* | 1.06 | 1.24\*\* |
| 4 | 0.99 | 1.07\*\* | 0.94\*\*\* | 1.00 | 1.01 | 0.99 | 1.15\*\* | 0.88\*\* | 1.00 | 1.08\*\* | 1.09 |
| 5 | 1.12\*\* | 1.06 | 1.01 | 1.12 | 0.80\*\*\* | 0.99 | 1.12 | 0.90 | 1.13 | 0.89 | 1.42\*\*\* |
| 6 | 1.02 | 1.03 | 0.95 | 1.00 | 1.01 | 1.03 | 0.96\*\* | 1.05\*\* | 0.96\*\* | 1.15\*\*\* | 1.26 |
| 7 | 1.35\*\*\* | 0.78 | 1.16\*\*\* | 0.99 | 0.94 | 0.86\*\*\* | 1.00 | 1.05\*\* | 1.65\*\*\* | 0.62\*\*\* | 0.95 |
| 8 | 0.82 | 1.13\*\* | 0.98 | 0.84\*\* | 0.90 | 1.58\*\*\* | 0.63\*\*\* | 1.07 | 1.14\*\* | 1.06 | 1.09 |
| 9 | 1.00 | 1.00 | 1.00 | 1.13\*\* | 0.89\*\* | 1.17\*\* | 0.85\*\*\* | 1.18\*\*\* | 1.04 | 0.82\*\*\* | 1.39\*\* |
| 10 | 1.02 | 0.72\*\*\* | 1.20\*\* | 1.81\*\*\* | 0.64\*\*\* | 0.99 | 0.90 | 0.80 | 1.20\*\* | 2.00\*\*\* | 0.73 |
| 11 | 1.02 | 1.17\*\*\* | 0.89\*\* | 1.06 | 0.95 | 1.06 | 0.99 | 1.01 | 0.98 | 0.93 | 1.32\*\*\* |
| 12 | 0.91 | 0.98 | 0.99 | 1.11 | 0.90 | 1.24\*\*\* | 0.81\*\*\* | 1.12\*\* | 1.06 | 1.12 | 1.09 |
| 13 | 0.80\*\* | 0.90 | 1.00 | 1.00 | 1.29\*\*\* | 0.91 | 0.91 | 0.96\*\* | 0.99 | 0.99 | 1.00 |
| 14 | 1.00 | 1.09\*\* | 0.92\*\*\* | 1.20 | 0.83 | 1.33\*\*\* | 0.92 | 1.33\*\*\* | 0.65\*\*\* | 1.20\*\* | 1.22 |
| 15 | 1.10 | 1.00 | 1.02 | 0.88\*\* | 1.03 | 1.03 | 0.96 | 0.96 | 0.99 | 1.01 | 1.76\*\*\* |
| 16 | 1.13\*\*\* | 1.18\*\* | 1.10 | 0.93 | 1.07 | 0.81 | 0.94 | 0.93 | 1.10\*\* | 1.10\*\* | 1.02 |
| 17 | 1.09\*\*\* | 0.99 | 0.97 | 0.95\*\* | 1.03 | 1.04 | 0.93 | 1.07 | 1.00 | 0.98 | 1.10 |
| 18 | 1.00 | 1.07 | 0.94 | 1.00 | 1.00 | 1.00 | 1.02 | 0.98 | 1.00 | 1.00 | 1.07\*\* |
| 19 | 1.04\*\*\* | 1.05 | 1.03 | 0.89\*\*\* | 1.25\*\*\* | 0.91 | 0.92 | 1.00 | 1.04 | 1.45\*\*\* | 1.05 |
| 20 | 0.84\*\*\* | 0.90 | 1.52\*\*\* | 1.00 | 0.66\*\*\* | 1.17 | 0.94 | 0.91 | 1.18 | 0.85\*\* | 1.14\*\* |
| 21 | 0.98 | 0.95 | 1.04 | 1.23\*\*\* | 0.78\*\*\* | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.07 |
| 22 | 1.14\*\*\* | 0.93 | 0.99 | 0.98 | 0.97\*\*\* | 1.06\*\*\* | 0.94\*\*\* | 1.00 | 1.05 | 0.95 | 1.06 |
| 23 | 0.94 | 0.97 | 1.00 | 1.00 | 1.25\*\*\* | 0.98 | 0.91 | 1.04 | 0.97 | 0.99 | 1.42\*\*\* |
| 24 | 1.07 | 1.02 | 0.91\*\*\* | 1.11\*\* | 0.95 | 1.02 | 0.98 | 1.01 | 1.10 | 0.89 | 1.27\*\*\* |
| 25 | 1.03 | 0.97 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.24 | 0.81\*\* | 1.01 |
| 26 | 1.00 | 1.02 | 0.98 | 1.00 | 1.00 | 1.00 | 1.00 | 1.43\*\*\* | 1.28 | 0.56\*\*\* | 0.97 |
| 27 | 1.05 | 0.96 | 1.19\*\*\* | 0.83\*\*\* | 1.07\*\* | 1.05 | 0.89\*\* | 1.03 | 1.10 | 0.91 | 1.15\*\*\* |
| 28 | 1.00 | 1.00 | 1.05 | 0.95 | 1.12 | 1.21 | 0.82\*\* | 1.17 | 0.79\*\* | 0.97 | 1.66\*\*\* |
| 29 | 1.00 | 1.09\*\* | 0.92\*\* | 1.52\*\*\* | 0.71\*\*\* | 1.11 | 1.06 | 1.11 | 0.72\*\*\* | 1.09\*\* | 0.90\*\*\* |
| 30 | 0.88\*\*\* | 1.06 | 0.95 | 1.06 | 1.01 | 0.93\*\*\* | 1.00 | 1.00 | 1.18\*\*\* | 0.85\*\*\* | 1.52\*\*\* |
| 31 | 1.21 | 0.69\*\*\* | 1.00 | 1.12\*\* | 1.20 | 0.74\*\*\* | 1.35\*\* | 0.74\*\*\* | 1.00 | 1.01 | 2.20\*\*\* |
| 32 | 1.11\*\* | 0.90\*\* | 1.00\*\* | 1.00 | 1.00 | 1.00 | 1.01 | 0.99 | 1.04 | 0.98 | 1.07\*\* |
| 33 | 1.42\*\*\* | 0.56\*\*\* | 1.38\*\*\* | 0.72\*\*\* | 1.07 | 1.22 | 0.76\*\*\* | 1.00 | 1.01 | 0.99 | 1.00 |
| 34 | 1.20 | 0.87 | 1.07 | 0.89 | 1.27\*\*\* | 0.79\*\*\* | 1.14\*\* | 1.16 | 0.76\*\* | 1.00 | 1.00 |
| 35 | 0.81\*\*\* | 1.05 | 1.72\*\*\* | 0.89 | 0.63\*\*\* | 1.32 | 0.88 | 1.23\*\* | 0.70\*\*\* | 1.16\*\*\* | 0.86\*\*\* |
| 36 | 0.84\*\* | 1.17 | 0.85 | 1.19 | 0.93 | 0.91 | 1.02 | 1.45\*\*\* | 0.74\*\* | 1.07 | 1.25\*\* |
| 37 | 1.00 | 1.09\*\*\* | 0.92\*\*\* | 1.02\*\* | 1.01 | 1.01 | 0.97 | 0.99 | 1.07\*\* | 0.93\*\* | 1.24\*\*\* |
| 38 | 1.00 | 1.06 | 1.17 | 0.82 | 1.63\*\*\* | 0.73\*\*\* | 0.82 | 1.00 | 1.37\*\*\* | 0.73\*\* | 1.01 |
| 39 | 1.00 | 1.00 | 1.00 | 1.21 | 0.82 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 |
| 40 | 1.43\*\*\* | 0.91 | 0.72\*\*\* | 1.66\*\*\* | 0.67\*\*\* | 1.17 | 0.98 | 0.99 | 0.89 | 1.00 | 0.89 |
| 41 | 1.25\*\* | 0.95 | 1.20\*\* | 0.83 | 0.91 | 1.08 | 1.66\*\*\* | 0.73 | 0.99 | 1.37\*\*\* | 1.05 |
| 42 | 1.23\*\*\* | 0.82\*\* | 0.98\*\* | 1.06\*\*\* | 0.94\*\*\* | 1.16\*\*\* | 0.86\*\*\* | 1.01 | 0.99 | 1.00 | 1.03 |
| 43 | 0.98 | 1.00\*\*\* | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 |
| 44 | 1.06 | 0.95 | 0.97 | 1.01 | 1.09 | 0.94 | 0.99 | 1.17\*\*\* | 0.85\*\*\* | 0.99 | 1.18\*\*\* |
| 45 | 1.01 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.11 | 0.97 |
| 46 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.03 |
| 47 | 1.04 | 0.94 | 0.94 | 1.02 | 1.08 | 0.86\*\*\* | 1.07 | 1.01 | 0.95 | 0.93\*\*\* | 1.22\*\*\* |
| 48 | 0.77 | 1.17 | 1.33\*\* | 1.50\*\*\* | 0.80\*\*\* | 1.09 | 0.67\*\*\* | 1.21 | 0.78\*\* | 1.15 | 1.38\*\* |
| 49 | 1.06 | 0.95 | 1.02 | 1.01 | 1.24\*\*\* | 0.80\*\*\* | 1.04 | 1.06 | 0.97 | 1.02 | 1.19 |
| 50 | 0.89\*\*\* | 1.21\*\*\* | 1.21 | 0.83\*\* | 0.87 | 1.00 | 0.99 | 0.76\*\*\* | 1.24\*\*\* | 1.10 | 1.01 |
| 51 | 1.00\*\*\* | 1.00 | 1.00 | 1.00 | 1.00\*\*\* | 1.00\*\*\* | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 |
| 52 | 1.13 | 0.89 | 1.11 | 0.82 | 1.11 | 1.10 | 0.63\*\*\* | 1.82\*\*\* | 0.72\*\*\* | 1.05 | 1.25 |
| 53 | 0.62\*\*\* | 1.02 | 1.19 | 1.20\*\* | 0.88 | 1.12 | 0.94 | 0.75\*\*\* | 1.09 | 1.22\*\*\* | 0.87 |
| 54 | 1.05 | 0.98 | 0.97 | 1.03\*\*\* | 0.99 | 1.18\*\*\* | 0.85\*\* | 0.99 | 1.09 | 1.24\*\*\* | 1.43 |
| 55 | 1.04 | 1.00 | 0.90\*\*\* | 1.09\*\*\* | 0.99 | 0.92\*\*\* | 1.03 | 1.02 | 0.95 | 1.00 | 1.45\*\*\* |
| 56 | 1.03 | 0.84 | 0.91\*\* | 1.06\*\* | 0.93\*\*\* | 1.07\*\* | 1.04 | 0.90\*\*\* | 1.11\*\*\* | 0.91\*\*\* | 1.27\*\*\* |
| 57 | 1.01 | 1.21\*\*\* | 1.17 | 0.89 | 0.82\*\* | 0.85\*\*\* | 0.99 | 1.03 | 1.20\*\*\* | 0.82\*\*\* | 0.99 |
| 58 | 1.14 | 0.93 | 0.90\*\*\* | 1.09\*\*\* | 1.09 | 1.00 | 0.91 | 1.12\*\* | 0.91 | 0.98 | 1.24\*\*\* |
| 59 | 0.97\*\*\* | 1.17\*\*\* | 1.12 | 0.99 | 0.77\*\*\* | 1.07 | 0.93 | 1.00 | 1.03 | 1.03 | 1.03 |
| 60 | 1.14 | 0.84\*\* | 1.09 | 0.94 | 0.85\*\*\* | 1.17 | 1.30\*\* | 0.70\*\*\* | 1.03 | 0.91\*\* | 1.36\*\*\* |

\*\* Significantly different from unity at 0.05 level

\*\*\* Significantly different from unity at 0.01 level

1. Superscripts are used to denote the different farms and subscripts to denote the different types of inputs and outputs. Note that in the absence of subscripts we consider all inputs and outputs in a vector format [↑](#footnote-ref-1)