APPLIED ECONOMICS LETTERS, 2016
VOL. 23, NO. 2, 132–137
http://dx.doi.org/10.1080/13504851.2015.1058897

Routledge
Taylor & Francis Group

Effects of food and agricultural imports on domestic factors in the U.S. agricultural sector: a translog cost function framework

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ABSTRACT
The translog cost function of the U.S. agricultural sector unveils dynamic relationships between foreign and domestic inputs. On average, capital and labour are weak substitutes, but they are strong substitutes to food and agricultural imports. Therefore, enhancing trade policies on food and agricultural products should be supplemented by strategic policies aiming at protecting domestic factors' income.

KEYWORDS
Translog cost function; food imports; agricultural imports; United States

JEL CLASSIFICATION
C32; J480; O330; Q170

I. Introduction

Numerous methods have been used to investigate the relationships between domestic production inputs in the U.S. agricultural and food industry. Ray (1982) used the translog cost function of the U. S. Agricultural production from 1939 to 1970 and found that there is a declining trend in the degree of substitutability between capital and labour, the price elasticity of demand for all inputs increased overtime. Huang (1991) used the Morishima elasticities to analyse demand for labour, capital and energy in the U.S. food manufacturing industry. His results showed that capital is more elastic than the two other factors, and all the three factors are substitutes. Extending the work of Huang, Goodwin and Brester (1995) incorporated raw materials as a factor of production and considered the structural shift in the factor demand relationships, and then found that all the factors are substitutes and the degree of substitutability constantly increased before 1995.

This article intends to analyse potential impacts of trade policies on the U.S. agricultural sector, using a translog cost function framework. To our best knowledge, the translog scheme has not been used to analyse implications of trade policies in the U.S. agricultural sector. By so doing, the article will give more insights to policymakers on incidence of enhancing and or restrictive trade policies on the U.S. agricultural, in a holistic perspective. Our findings are consistent with the widely reported stories in the area. As an illustration, Barkema, Henneberry, and Drabenstott (1989) asserted that trade liberalization in agriculture will make farmers suffer in some other countries, but the gains to consumers will offset those losses. Thus, 'strikingly new methods of supporting farm incomes would be required' (p. 4). Therefore, based on data related to domestic (capital, labour and miscellaneous) and foreign (food imports and agricultural imports) agricultural inputs in the United States, it is brought to light that capital and labour were substitutes, and then became complement since 2006, while both capital and labour are increasingly substitutes to foods and agricultural imports.

II. Data and econometric methodology

This study covers the period from 1978 to 2011. Apart from the food imports information that comes from the World Development Indicator (WDI) database, all the other data are computed or retrieved from the U.S. Department of Agriculture (USDA). The annual agricultural price index is the average of annual agricultural products' price indexes. Values of agricultural imports are the summation of monthly imports, divided by the annual price index. The monthly price index of

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imported foods is averaged to get the annual price index. The value of food imports is the percentage of imported foods in merchandise multiplied by the total value of merchandise from WDI. Therefore, the quantity of imported food is found by dividing the food imports and the price index. According to USDA, capital is composed of durable equipment, service buildings, land and inventories; labour is composed of hired labour and self-employed, and miscellaneous is composed of farm origin, energy, fertilizer, pesticides, purchased services and other intermediates.

Therefore, assuming that there exists in the United States agricultural sector a twice differentiable aggregate production function linking the flow of gross output to the services of three domestic inputs – capital (K), labour (L) and miscellaneous (O) – and of two foreign inputs – food and agricultural imports(M). We also assume that production processes have constant returns to scale and that any technical change transmitted to K, L, O and M is Hicks-neutral. Moreover, there exists a cost function which echoes the production technology. The cost function can be implicitly written as $C = \emptyset(Y, P_k, P_l, P_o, P_m, T)$, where C is the total cost; Y is the output; P_k, P_l, P_o and P_m are inputs prices of K, L, O and M, respectively; and T[1] denotes technology.

Likewise Berndt and Wood (1975) this article specifies a translog cost function, which is a highly general functional form of C without *ex ante* restrictions on the Allen partial elasticities of substitution (AES) and to be interpreted as a second-order approximation of an arbitrary twice-differentiable cost function. The related cost function with symmetry and constant returns to scale can be written, with lower cases being the log forms, as

$$c = \alpha_0 + \alpha_y y + \alpha_t t + \sum_i p_i \left(\beta_i + \frac{1}{2} \sum_j \theta_{ij} p_j + \theta_{iy} y + \gamma_{it} t \right) + \frac{1}{2} \left(\alpha_{tt} t^2 + \alpha_{yy} y^2 \right) + \alpha_{yt}\, yt \quad (1)$$

with i and j = K, L, O, M.

Linear homogeneity in prices imposes the following restrictions on Equation 1

$$\sum_i \beta_i = 1; \sum_j \theta_{ij} = 0; \sum_i \theta_{it} = 0; \sum_i \theta_{iy} = 0 \quad (2)$$

With perfect competition in the factor markets, input prices can be treated as given. For a given level of output, costs minimizing input demand functions are derived in the following way. Differentiating in log and using the Shephard's lemma, we obtain the input demand equations:

$$\frac{\partial c}{\partial p_i} = \frac{\partial C}{\partial P_i} \frac{P_i}{C} = \beta_i + \sum_j \theta_{ij} p_j + \theta_{iy} y + \theta_{it} t \quad (3)$$

The AES between inputs, as originally derived by Uzawa (1962), can be obtained using the following expressions:

$$\epsilon_{ij} = \frac{\theta_{ij} + S_i S_j}{S_i S_j} \quad \text{with } i \neq j \quad (4)$$

If $\epsilon_{ij} > 0$, then inputs i and j are substitutes for each other, and they are complements for the opposite case.

The system composed of the four demand equations represented by Equation 3 can be estimated after adding an error term.

$$S_i = \frac{P_i I}{C} = \beta_i + \sum_j \theta_{ij}\, p_j + \theta_{iy}\, y + \theta_{it}\, t + \mu_i \quad (5)$$

Given that the shares add up to 1 or 100%, random disturbances of the four equations would sum up to zero. Therefore, disturbances of the four equations are not independent anymore. Thus, the seemingly unrelated regressions (SUR) method is appropriate to estimate the system. However, the dependence of disturbances makes the variance-covariance matrix of the SUR procedure not invertible. Thus, the system cannot be estimated without deleting one equation.[2] Fortunately, using the iterative SUR estimation method will make our estimates invariant of which equation is deleted. As Sharma (1991) did, the residuals from each estimated equation are analysed using the autocorrelation function and the partial autocorrelation function to determine the error model. Although residual terms have different structure, we assume that all the errors follow an AR (1) process to keep consistency across all the equations.

[1]Time trend is used as a proxy of technology like in Sharma (1991).
[2]The prices in the remaining equations are expressed in relative terms with respect to the price related to the input share deleted.

Therefore, the corrected Equation 6 is estimated and reported in the 'Empirical results' section.

$$S_{it} = \beta_i + \sum_j \theta_{ij} p_{jt} + \theta_{iy} y_t + \theta_{it} t_t - \rho_i \left(\beta_i + \sum_j \theta_{ij} p_{jt-1} + \theta_{iy} y_{t-1} + \theta_{it} t_{t-1} \right) + \mu_{it} \quad (6)$$

Parameters of the deleted equation are recovered by the use of linear restrictions imposed to the original system.

III. Empirical results

Two variants of Equation 6 are estimated: the first one uses food imports while the second one uses agricultural imports. Models I and III are estimated with no restriction on θ_{iy} in order for the production function to be nonhomothetic[3]; Models II and IV assume the production function is homothetic. The production function would be homothetic (nonhomothetic) if θ_{iy} is statistically insignificant (significant). The empirical results, reported in the Appendix, show that the production function is homothetic, regardless of whether M represents food or agricultural imports. As far as agricultural imports are concerned, the production technology is robustly capital-saving, import using and miscellaneous neutral.

The values of the elasticities are computed with Equation 4, using estimated parameters of Equation 6, as reported in Table 1, and fitted values of input shares. From Model I it can be seen that capital and labour were substitutes before and became complement since 2006; capital and miscellaneous became complement since 1993, the substitutability between capital and food imports is increasing overtime; food imports became substitutes to miscellaneous since 1994; the substitution behaviour between miscellaneous and foods imports is relatively stable; and the association between labour and foods imports is similar to the one between capital and foods imports.

Model II reveals that capital and labour became complements since 2006, while capital and miscellaneous became complements since 1994. Labour and capital are becoming more and more substitute to foods imports; miscellaneous became substitutes to foods imports since 1997; and the substitution behaviour between labour and miscellaneous is relatively stable.

Model III shows a decreasing substitutability between capital and labour. In addition to that, capital and miscellaneous were substitute since 1981 and became complement since 1994, and the substitution behaviour between capital and agricultural imports and between agricultural imports and miscellaneous is increasing overtime. The substitutability between miscellaneous and labour is relatively stable while labour and capital seem to have the same type of association with agricultural imports.

Model IV reveals that capital and labour have changed from being substitutes to being complements since 2006; the same change is observed between capital and miscellaneous since 1994; the substitutability between capital and agricultural imports has an increasing trend; the substitutability between miscellaneous and agricultural imports is also increasing; labour is substitute to miscellaneous during the whole period observed and labour and imports are becoming more substitutes.

Table 2 reports average elasticities of substitution between inputs in the U.S. agricultural sector. On average, capital tends to be a weak[4] substitute to labour, strong substitute to imports and weak complement to miscellaneous. Labour tends to be a strong substitute to imports and miscellaneous. The latter is revealed to be a strong substitute to agricultural imports, but a weak substitute to food imports.

Table 1. Average elasticities.

Elasticities	Model I	Model II	Model III	Model IV
ϵkl	0.1131	0.1058	0.2700*	0.0540
ϵkm	0.0139*	0.0088	0.0100*	0.0090
ϵko	−0.1792	−0.0700	−0.1302	−0.0808
ϵlm	0.6416*	0.7017*	0.5628*	0.7170*
ϵlo	0.2942*	0.2850*	0.2883*	0.2851*
ϵmo	0.0915	−0.0259	0.4860*	0.4319*

Note: * denotes statistically significant.

[3]The production function is nonhomothetic when the technical marginal rate of substitution is different from zero.

[4]The concept of weak (strong) substitute or complement is related to the fact that the average elasticities are not statistically significant (statistically significant) (Sharma 1991).

Table 2. Estimations of Equation 6.

Parameters	Model I	Model II	Model III	Model IV
βk	0.2962	0.0953	0.1736	0.3519***
βl	0.2785	0.2414***	0.6672***	0.3526***
βm	1.2310	0.3935	−0.0212	−0.0921***
βo	−0.8058	0.2698	0.1804	0.3875****
Θkl	−0.0290***	−0.0292***	−0.0257***	−0.0333***
Θkm	−0.0166**	−0.0232***	−0.0141*	−0.0157***
Θkk	0.1629***	0.1589***	0.1593***	0.1633***
Θll	0.0852***	0.0848***	0.0862***	0.0911***
Θlm	−0.0079	−0.0066	−0.0084	−0.0054
Θmm	0.0878***	0.1013***	0.0529***	0.0548***
Θok	−0.1174****	−0.1065****	−0.1196****	−0.1143****
Θol	−0.0483****	−0.0490****	−0.0522****	−0.0525****
Θom	−0.0633****	−0.0714****	−0.0305	−0.0337
Θoo	0.2290****	0.2269****	0.2022****	0.2005****
Θky	−0.0157		0.0174	
Θly	−0.0026		−0.0312	
Θmy	−0.0261		−0.0071	
Θoy	0.0444		0.0210	
ΘkT	0.0181	0.0126	−0.0606***	−0.0486***
ΘlT	−0.0027	−0.0033	−0.0303	−0.0543***
ΘmT	−0.0021	−0.0064	0.0846***	0.0788***
ΘoT	−0.0133	−0.0029	0.0063	0.0241
ρ1	0.9500***	0.9627***	0.5595***	0.5295***
ρ2	1.0377***	1.0437***	0.7625***	0.7624***
ρ3	0.9934***	0.9793***	0.6898***	0.6886***
Equation 1 adj R^2	0.9709	0.9723	0.9797	0.9799
Equation 2 adj R^2	0.9173	0.9203	0.9176	0.9203
Equation 3 adj R^2	0.9757	0.9735	0.9567	0.9578
Observations	33	33	31	31

Notes: *, ** and *** denote statistical significance at 10%, 5% and 1%. And **** denotes statistically significance of the parameters computed manually using related initial restrictions. Models I and II are related to food imports while models III and IV are related to agricultural imports.

IV. Conclusions

This article adds food and agricultural imports to the lists of production factors in the U.S. agricultural sector, and the translog cost function as well as its econometric corollaries are applied to data from 1978 to 2011 .Therefore, capital and labour were substitutes, and then became complement since 2006, while both capital and labour are substitutes to foods and agricultural imports and that behaviour is becoming more pronounced overtime. Moreover, all the models have also revealed a change in the relationship between miscellaneous and imports since 1994. On average, capital and labour are weak substitutes towards each other, but they are strong substitutes to foods and agricultural imports. Labour is a strong substitute to miscellaneous, the latter is a strong substitute to agricultural imports. Thus, policymakers and researchers should be wary of potential impact of trade restrictions on domestic factors. More specifically, our empirical findings suggest that removal of restrictions on U.S. food and agricultural imports should be accompanied by some domestic policies in the agricultural sector to protect domestic factor's income.

Disclosure Statement

No potential conflict of interest was reported by the author.

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Appendix: Elasticities

Table A1. Annual elasticities from Model I.

Year	ϵkl	ϵkm	ϵko	ϵlm	ϵlo	ϵmo
1979	0.212	0.005	0.088	0.484	0.280	−0.175
1980	0.011	0.005	−0.053	0.525	0.346	0.006
1981	0.079	0.004	0.120	0.380	0.221	−0.165
1982	0.221	0.005	0.067	0.499	0.313	−0.180
1983	0.061	0.005	0.028	0.474	0.305	−0.069
1984	0.178	0.006	0.149	0.416	0.170	−0.187
1985	0.264	0.009	0.103	0.531	0.192	−0.123
1986	0.264	0.013	0.089	0.570	0.121	−0.047
1987	0.273	0.013	0.091	0.572	0.109	−0.052
1988	0.180	0.010	0.032	0.578	0.231	0.020
1989	0.281	0.009	0.068	0.564	0.250	−0.111
1990	0.346	0.009	0.043	0.606	0.274	−0.134
1991	0.259	0.010	−0.002	0.619	0.288	−0.012
1992	0.317	0.010	0.047	0.600	0.252	−0.096
1993	0.264	0.010	−0.023	0.630	0.314	−0.012
1994	0.231	0.011	−0.034	0.633	0.301	0.032
1995	0.218	0.010	−0.235	0.706	0.427	0.088
1996	0.278	0.009	−0.115	0.666	0.401	−0.014
1997	0.240	0.012	−0.161	0.697	0.372	0.091
1998	0.181	0.015	−0.275	0.730	0.391	0.173
1999	0.107	0.015	−0.336	0.735	0.393	0.222
2000	0.026	0.013	−0.497	0.751	0.445	0.247
2001	0.098	0.015	−0.432	0.756	0.422	0.238
2002	−0.148	0.013	−0.818	0.782	0.475	0.320
2003	0.154	0.022	−0.421	0.776	0.375	0.259
2004	0.227	0.023	−0.261	0.754	0.308	0.211
2005	0.069	0.022	−0.453	0.770	0.369	0.294
2006	−0.205	0.020	−0.852	0.794	0.425	0.378
2007	−0.058	0.029	−0.391	0.751	0.250	0.356
2008	−0.201	0.025	−0.302	0.699	0.201	0.359
2009	−0.419	0.021	−0.785	0.764	0.361	0.417
2010	−0.103	0.029	−0.275	0.714	0.173	0.349
2011	−0.173	0.031	−0.117	0.646	−0.047	0.337
Average	0.113	0.014	−0.179	0.642	0.294	0.091

Table A2. Annual elasticities from Model II.

Year	ϵkl	ϵkm	ϵko	ϵlm	ϵlo	ϵmo
1979	0.207	0.003	0.171	0.574	0.270	−0.320
1980	0.004	0.001	0.045	0.606	0.336	−0.120
1981	0.073	0.002	0.205	0.475	0.213	−0.335
1982	0.214	0.002	0.154	0.581	0.304	−0.335
1983	0.055	0.001	0.119	0.562	0.296	−0.210
1984	0.169	0.003	0.227	0.514	0.161	−0.339
1985	0.254	0.006	0.188	0.605	0.185	−0.274
1986	0.254	0.009	0.172	0.642	0.113	−0.177
1987	0.268	0.010	0.175	0.644	0.098	−0.189
1988	0.179	0.007	0.123	0.651	0.217	−0.106
1989	0.278	0.006	0.155	0.638	0.239	−0.256
1990	0.342	0.007	0.129	0.675	0.263	−0.274
1991	0.252	0.007	0.090	0.684	0.279	−0.141
1992	0.311	0.007	0.135	0.667	0.244	−0.238
1993	0.260	0.006	0.072	0.693	0.304	−0.142
1994	0.226	0.008	0.058	0.700	0.289	−0.083
1995	0.211	0.006	−0.125	0.758	0.418	−0.023
1996	0.275	0.005	−0.008	0.721	0.393	−0.151
1997	0.234	0.008	−0.055	0.749	0.363	−0.024
1998	0.168	0.009	−0.160	0.774	0.386	0.066
1999	0.095	0.009	−0.213	0.779	0.387	0.120
2000	0.021	0.006	−0.353	0.792	0.437	0.148
2001	0.092	0.009	−0.295	0.796	0.415	0.136
2002	−0.165	0.003	−0.654	0.818	0.470	0.233
2003	0.144	0.015	−0.291	0.813	0.369	0.164
2004	0.222	0.017	−0.146	0.796	0.297	0.109
2005	0.060	0.015	−0.319	0.809	0.361	0.204
2006	−0.211	0.010	−0.676	0.829	0.417	0.297
2007	−0.057	0.022	−0.259	0.794	0.238	0.271
2008	−0.202	0.018	−0.178	0.751	0.187	0.276
2009	−0.450	0.009	−0.624	0.802	0.355	0.341
2010	−0.118	0.021	−0.157	0.760	0.167	0.265
2011	−0.173	0.026	−0.014	0.708	−0.065	0.252
Average	0.106	0.009	−0.070	0.702	0.285	−0.026

Table A3. Annual elasticities from Model III.

Year	ϵkl	ϵkm	ϵko	ϵlm	ϵlo	ϵmo
1981	0.241	0.004	0.152	0.271	0.146	0.363
1982	0.361	0.003	0.102	0.364	0.286	0.302
1983	0.239	0.002	0.074	0.296	0.297	0.330
1984	0.343	0.003	0.190	0.192	0.174	0.221
1985	0.401	0.004	0.139	0.373	0.216	0.296
1986	0.398	0.006	0.127	0.438	0.166	0.362
1987	0.402	0.007	0.132	0.445	0.136	0.370
1988	0.321	0.006	0.074	0.456	0.234	0.420
1989	0.392	0.006	0.102	0.447	0.229	0.361
1990	0.439	0.006	0.076	0.498	0.261	0.353
1991	0.380	0.006	0.035	0.516	0.289	0.411
1992	0.424	0.007	0.077	0.503	0.240	0.377
1993	0.375	0.007	0.002	0.549	0.306	0.437
1994	0.354	0.008	0.003	0.551	0.283	0.459
1995	0.327	0.008	−0.178	0.635	0.401	0.501
1996	0.378	0.008	−0.077	0.608	0.351	0.469
1997	0.342	0.010	−0.119	0.634	0.343	0.514
1998	0.316	0.010	−0.210	0.667	0.380	0.540
1999	0.271	0.011	−0.258	0.676	0.383	0.564
2000	0.225	0.010	−0.382	0.694	0.433	0.573
2001	0.264	0.010	−0.341	0.697	0.420	0.568
2002	0.068	0.008	−0.684	0.724	0.481	0.611
2003	0.296	0.014	−0.324	0.715	0.389	0.581
2004	0.376	0.015	−0.167	0.694	0.303	0.552
2005	0.246	0.016	−0.354	0.720	0.370	0.607
2006	0.033	0.014	−0.701	0.749	0.429	0.654
2007	0.134	0.021	−0.300	0.700	0.261	0.647
2008	0.051	0.019	−0.215	0.647	0.199	0.647
2009	−0.143	0.015	−0.701	0.725	0.380	0.680
2010	0.082	0.021	−0.238	0.669	0.205	0.651
2011	0.030	0.025	−0.071	0.594	−0.054	0.650
Average	0.270	0.010	−0.130	0.563	0.288	0.486

Table A4. Annual elasticities from Model IV.

Year	ϵkl	ϵkm	ϵko	ϵlm	ϵlo	ϵmo
1981	−0.003	0.004	0.195	0.514	0.126	0.296
1982	0.174	0.003	0.133	0.598	0.290	0.237
1983	0.018	0.002	0.114	0.546	0.296	0.258
1984	0.150	0.002	0.223	0.480	0.173	0.141
1985	0.220	0.004	0.177	0.593	0.211	0.224
1986	0.213	0.006	0.169	0.631	0.154	0.295
1987	0.224	0.007	0.171	0.639	0.128	0.302
1988	0.129	0.005	0.112	0.651	0.235	0.357
1989	0.217	0.005	0.140	0.644	0.228	0.292
1990	0.277	0.005	0.112	0.679	0.262	0.287
1991	0.194	0.006	0.080	0.684	0.282	0.348
1992	0.251	0.006	0.121	0.675	0.232	0.310
1993	0.190	0.006	0.045	0.707	0.302	0.377
1994	0.167	0.007	0.044	0.711	0.282	0.401
1995	0.130	0.007	−0.127	0.764	0.398	0.448
1996	0.195	0.007	−0.028	0.745	0.347	0.411
1997	0.148	0.009	−0.069	0.763	0.339	0.462
1998	0.110	0.009	−0.150	0.782	0.372	0.491
1999	0.053	0.010	−0.192	0.788	0.375	0.517
2000	−0.002	0.008	−0.323	0.802	0.430	0.528
2001	0.045	0.009	−0.279	0.803	0.415	0.522
2002	−0.210	0.006	−0.598	0.820	0.476	0.569
2003	0.084	0.012	−0.259	0.814	0.382	0.537
2004	0.193	0.014	−0.122	0.803	0.303	0.505
2005	0.022	0.014	−0.294	0.818	0.366	0.565
2006	−0.254	0.012	−0.634	0.838	0.428	0.618
2007	−0.115	0.019	−0.250	0.808	0.264	0.609
2008	−0.214	0.018	−0.172	0.776	0.207	0.609
2009	−0.495	0.013	−0.637	0.822	0.378	0.648
2010	−0.201	0.019	−0.178	0.782	0.195	0.614
2011	−0.233	0.024	−0.032	0.744	−0.039	0.612
Average	0.054	0.009	−0.081	0.717	0.285	0.432