Using a structural gravity model to assess the risk of livestock disease incursions in the UK

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Abstract

A structural gravity model of UK livestock trade is developed and employed to assess the risk of possible disease incursions into the UK. Gravity models have been employed for a number of years in the econometric literature on international trade with considerable success. They involve modeling international trade by incorporating spatially explicit information into a model of the flow of traded goods between nations. Structural gravity models differ slightly from the naïve gravity model by developing a structural econometric model from an explicit theoretical model of consumer decision-making and this then results in the incorporation of multilateral trade resistance terms into the gravity equation. Such models have made considerable methodological advances in recent years. Gravity models have also been developed by epidemiologists to model the spatial spread of diseases between different populations. In this paper I develop a model that combines these two different approaches by using a combined panel dataset of livestock trade and disease incidence for the UK. Epidemiological variables are built into a theoretical model of individual consumer and producer decision-making and the corresponding structural gravity equation is derived. This is then estimated econometrically.

Keywords: structural econometrics, structural gravity model, spatial econometrics, livestock disease

1. Introduction

In this paper structural gravity model of UK livestock trade is developed and employed to assess the risk of possible disease incursions into the UK. Gravity models have been employed for a number of years in the econometric literature on international trade with considerable success. They involve modelling international trade by incorporating spatially explicit information into a model of the flow of traded goods between nations. Structural gravity models differ slightly from the naïve gravity model by developing a structural econometric model from an explicit theoretical model of consumer decision-making and this then results in the incorporation of multilateral trade resistance terms into the gravity equation. Such models have made considerable methodological advances in recent years. Gravity models have also been developed by epidemiologists to model the spatial spread of diseases between different populations. In this paper I develop a model that combines these two different approaches by using a combined panel dataset of livestock trade and disease incidence for the UK and it's trading partners. Epidemiological variables are built into a theoretical model of individual consumer and producer decision-making and the corresponding structural gravity equation is derived. This is then estimated econometrically.

The theory of structural gravity models was first developed by Anderson (1979) who introduced multilateral resistance terms for trade into such a model, since-then their have been numerous contributions to international trade. Anderson, J. E., & van Wincoop, E. (2003) study the border puzzle (the apparent divergence between national and state cross-border international trade). Baltagi, B. H. et al. (2014) study panel data model of interantional trade using gravity models.

There are a few studies that apply a gravity modelling framework to agricultural trade. So for example Koo, W. W., Karemera, D., & Taylor, R. (1994) apply a gravity model to the study of the meat trade and Reuben, J.et al. (2014) develop a gravity model of live animal trade and meat-products trade. The atter however is not structural in nature nor does it include the impact of infectious disease or spatial spread of infectious diseases through trade as part of the analysis. Prehn, S.et al. (2012) discuss the use of structural gravity models in modelling agricultural trade flows Nevertheless this is a comparatively little explored area compared with the broader literature on international trade.

Epidemiologists have also employed gravity models. Barrios, J. et al. (2012) apply the gravity modelling approach to the analysis of disease risk and this is a partial motivation for the present paper. They provide a gravity model specification of disease risk as a function of area, distance and population parameters. Jongejans, E. (2014) consider the use of gravity models as a general model of dispersal in ecological systems including applications to disease ecology. Simini, F.et al (2012) discuss the use of gravity models for modelling spatial movement in ecology, Truscott J. and Ferguson NM (2012) consider the use of gravity models for modelling human mobility and it's impact on epidemics. Viboud, C. eta al (2006) and Xia, Y. et al. (2004) apply gravity models to influenza and measles spread respectively. Epidemiological and ecological gravity models however have not yet been able to incorporate frictions in the way that structural gravity models do so via multilateral resistance terms. Consequently they are likely to overestimate disease risk.

In order to estimate the impact of trade in live animals on the threat of disease risk from international sources there is a need to combine gravity models of trade with epidemiological gravity models and to do so in a way that accounts for trade frictions. This is the main purpose of this paper.

In the next section I discuss the model set-up. Section 3 discusses the data, section 4 estimation of the various models and section 5 the results and some implications of the work for policy and section 6 concludes.

2. Set-up

Gravity models are know to arise when complete specialization, CES preferences and iceberg trade costs. The theoretical set-up follows Anderson and van Wincoop (2003). The model set-up is a modifed version of we use Dixit-Stiglitz preferences for consumers.

Consumers in country i maximise a CES utility function subject to a budget constraint:

$$U_i = (\sum_j \sum_k X_{ijk}^{\frac{\rho-1}{\rho}})^{\frac{\rho}{\rho-1}}$$

subject to

$$\sum_j \sum_k p_{ijk} X_{ijk} = I_i$$

where

$$X_{ijk}$$

is the quantity of a good of type k consumed in country i

that originates in country j In our case this is livestock of a particular type k, e.g. beef, chicken, pigs, etc. Country i is the UK.

The Lagrangian is given by

$$L_n = (\sum_j \sum_k X_{ijk}^{\frac{\rho-1}{\rho}})^{\frac{\rho}{\rho-1}} + \lambda(I_i - \sum_j p_{ij}\,\tau_j X_{ijk})$$

The first-order conditions are

$$\frac{\partial L_n}{\partial c_{nj}} = (\sum_j X_{nj}^{\frac{\rho-1}{\rho}})^{\frac{\rho-(\rho-1)}{\rho-1}}(\frac{\rho}{\rho-1})(\frac{\rho-1}{\rho})(X_{nj})$$

We assume monopolistic competitive producers who maximize profit.

A monopolistic mark-up rule may be derived as follows

$$profit = p(Q)Q - cQ$$

$$\frac{dp}{dQ}Q + p(Q) - c = 0$$

$$\frac{dp}{dQ} + \frac{p(Q)}{Q} - \frac{c}{Q} = 0$$

$$\frac{dp}{dQ} = \frac{c}{Q} - \frac{p(Q)}{Q}$$

invert

$$\frac{dQ}{dp} = \frac{Q}{c - p(Q)}$$

multiply by

$$\frac{p(Q)}{Q}$$

to get

$$\sigma = -\frac{dQ}{dp}\frac{p(Q)}{Q} = -\frac{p(Q)}{c - p(Q)}$$

now rearrange to obtain

$$p(Q)$$

$$\sigma(p(Q) - c) = p(Q)$$

$$\sigma p(Q) - \sigma c = p(Q)$$

$$p(Q)(1 - \sigma) = -\sigma c$$

or

$$p(Q) = \frac{\sigma}{\sigma - 1}c$$

Introducing Iie-berg transportation costs $\tau_j > 1$ due to deaths on transportation of livestock.

The markup rule becomes

$$p_{nj}(Q) = \frac{\sigma}{\sigma - 1}c\tau_j$$

So we can use this mark-up rule in conjunction with demand and market clearing:

$$q_n = \sum_j X_{nj}^*$$

To obtain the following structural gravity model after some further simplification

3. Structural gravity equation model

$$X_{ijk} = \frac{Y_{ik}}{\Pi_{ik}^{-\theta_k}} \times D_{ijk}^{-\theta_k} \times \frac{E_{jk}}{P_{jk}^{-\theta_k}}$$

$$P_{jk}^{-\theta_k} = \sum_j \frac{Y_{ik} D_{ijk}^{-\theta_k}}{\Pi_{ik}^{-\theta_k}}$$

$$\Pi_{ik}^{-\theta_k} = \sum_i \frac{E_{jk} D_{ijk}^{-\theta_k}}{P_{jk}^{-\theta_k}}$$

The usual approach is to estimate the first of these using a Poisson Pseudo Maximum Likelihood and then using the estimated results solve the remaining two equations to obtain estimates for the multilateral resistance terms.

4. Data

Data were obtained from a number of publically available data sources. So for example live animal trade data are available from three different sources: HM Revenue Trade statistics, FAOSTAT and the UN Comtrade statistics. Comtrade data are particularly suited for estimating gravity models. As they consist of multilateral trade data and provide export import values and quantities. GDP data were obtained from the Penn world tables and disease incidence/outbreak data from the OIE (World Organisation for Animal Health) WAHID (World Animal Health Information Database). Other data concerning geographic distances latitudes and longitudes and cultural variables was obtained from CEPII. The latter data is commonly used in the estimation of gravity models of international trade. From the OIE data, a dataset of disease occurences by country and year was constructed and matched against the Comtrade trade-flow data and the CEPII data. This gave rise to an unbalanced panel data set covering the years 1993-2014 of all UK trade partners. Because trading partners fluctuate from year to year the panel is unbalanced. Special care needs to be taken when dealing with unbalanced panel data. One approach is the inclusion of attrition dummies for each country in the years in which they drop-out. Another approach is to estimate the model using random effects rather than fixed effects. The total number of observations obtained in the combined data set is 1479.

5. Estimation

We will use GLM to estimate this. Using GLM to estimate structural gravity models has been suggested by @Prehn2012 and @Egger2014.

The equation to estimate is the following

$$X_{ijk} = \exp\alpha_0 + e_{ik} - \theta_k D_{ijk} + m_j k + \varepsilon_{ijk}$$

where $m_{jk}$are import fixed effects and e_{ik}

are export fixed effects.

D_{ijk} captures bilateral trade costs between country i

and country $j$for livestock type k

.

Trade distance is approximated with a series of variables including dummy variables such as

- distance between countries.
- contiguity (border effect)
- colony
- language
- disease (as a trade barrier/source of infection)

We estimate this by the standard method of Poisson Pseudo Maximum Likelhihood (PPML) with fixed effects. As pointed out by Egger, P. H., & Staub, K. E. (2014) GLM (generalized linear models) estimators may be used as a unifying framework for the estimation of gravity models including PPML so this is the approach taken in this paper.

A number of approaches for estimation of the multilateral resistance terms may be used. In general we can distinguish between two-step and multi-step approaches. The usual first-step above is to estimate the gravity equation with fixed effects and then use the estimated fixed effects to calculate the multi-lateral resistance terms @Anderson2014. Some authors propose doing this iteratively by solving the auxiliary multi-lateral resistance equations to obtain updated distance estimates (@Head2014) and then re-estimating the gravity equation using these.

In this paper I follow the former of these two approaches which is the "gold standard" approach.

First stage gravity equation results are presented in the following regression table.

Table 1: First-stage Poisson Pseudo Maximum Likelihood Results for African Swine Fever

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Maximum Likelihood estimation

```
Newton-Raphson maximisation, 14 iterations
Return code 2: successive function values within tolerance limit
Log-Likelihood: -63671496
7  free parameters
Estimates:
             Estimate Std. error  t value  Pr(> t)
(Intercept)    1.482e+01  3.282e-01   45.155  < 2e-16 ***
ASF         -5.016e-01  1.914e-03 -262.022  < 2e-16 ***
contig       2.598e+00  2.285e+00    1.137 0.255489
comlang_ethno  8.170e-01  1.325e+00    0.616 0.537622
colony       1.728e+00  1.203e+00    1.436 0.150969
distcap      -1.991e-04  5.802e-05   -3.432 0.000598 ***
sigma        2.265e-01  2.860e-02    7.921 2.36e-15 ***
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
--------------------------------------------
```

These results are estimated for the period 2012-2014 sub-sample of the complete data set resulting in 197 observations. This is simply an example to illustrate the procedure. Furthermore in the above table only the impact of African Swine Fever is considered. A full analysis would consider other diseases and combinations of diseases. From the above table we can see that disease occurrence is significant as is distance and the standard deviation. However the low value of the dispersion parameter sigma indicates that the fit is not that good. My results are still very preliminary and I expect to obtain improved estimates on the larger sample.

6. Discussion

Our results show a negative impact of disease incidence for some diseases on trade-flows between UK trading partners and the UK. Because trade-flows are measured in dollars this indicates that the presence of African Swine fever in different countries has reduced trade with the UK. African swine fever has not been detected in the UK so we cannot interpret the results so far as a model of disease spread. However, because the value of livestock trade reflects actually physical movement in live animals we can interpret this negative impact asa reduction in the physical stock of livestock in the UK from African Swine Fever. Introduction of an additional dummy variable representing the joint presence of the disease in a source country and in the destination country would be a way of capturing the impact of the actual disease spread on the UK. In this case such a variable would play no role. We can however interpret the estimated trade flows following the epidemiology literature as a measure of the epidemiological risk and use this to construct a counterfactual risk analysis of the impact of disease occurences in particular countries on the UK economy.

Calculation of the multilateral resistance terms is still in progress however this is a relatively straightforward calculation and allows us to adjust the estimated impact of the disease on UK imports.

7. Conclusion

In this paper I have conducted a preliminary analysis of UK live animal trade using a gravity model of international livestock trade for example of African Swine Fever. The work is ongoing and I have data fro numerous other livestock diseases that are amenable to gravity model type analyses for the UK. The work is still in progress and very much preliminary.

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