NON-UNIFORM AND NON-CONSTANT TRANSACTION COSTS AS DETERMINANTS OF DISPERSED AGRICULTURAL TRADE FLOWS

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1. Introduction

In a 1952 article, Samuelson developed the theory that the problem of price relations between two spatially separated markets, described by him as a 'purely descriptive problem in non-normative economics', can be formulated as an optimization problem and be related to the Koopmans (1949) - Hitchcock (1941) minimum-transport-cost problem. We refer to this theory throughout the manuscript as the spatial price equilibrium (SPE) theory. The corresponding Enke – Samuelson – Takayama – Judge (ESTJ, Enke 1951; Samuelson 1952; Takayama and Judge 1964) SPE model has been widely applied in the past by agricultural economists for *ex-ante* analysis of agricultural trade policies. Some recent examples include (Abbassi et al. 2008; Anania 2006; Butt and McCarl 2005; Djunaidi and Djunaidi 2007; Helming and Reinhard 2009; Nolte et al. 2010; Sobolevsky et al. 2005; Weaver 2009; Wilson et al. 2008). In its most basic shape, it is a recursive combination of demand and supply models of various regions and a cost minimizing transport model between these regions. The transport module being normative and usually linear

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leads to sharp predictions of trade patterns with a very low number of trade flows. As a consequence, the SPE theory falls short of explaining observed behavior of countries engaged in international commodity trade and the model performs poorly in reproducing observed trade flows as several authors have pointed out (see the literature cited in section 2.1). However, since in a solution of the model, all possibilities for spatial arbitrage are exhausted, it has a high predictive power for regional prices, which is also confirmed by traders. Furthermore, for homogeneous or fungible commodities, it is the model that exhibits the most realistic simulation behavior. Both these reasons provide the rationale for its wide application despite the aforementioned drawbacks.

As a consequence of the mentioned shortcomings in addition to emerging trends in international agri-food trade, such as the growing importance of intra-industry trade, consumer concerns about food safety and the emergence of biotechnology in agriculture, Sarker and Surry (2006) argue that trade models resting on the assumption of homogeneous products will in future be ‘less and less suited to study trade in agri-food products’.

Recent evidence, however, shows that the assumption of product homogeneity might be indispensible for a proper theory of spatial commodity trade: In 2007 sugar refineries in the Persian Gulf switched from processing solely Brazilian raw sugar to using raw sugar from India for more than a year, after ocean freight costs had surged and a good harvest and political incentives made raw sugar from India competitive in that region. (ISO various issues). Any competing theory or model of spatial trade (see section 2 for details) would have necessarily failed to explain this complete switch after a change of relative prices. These models only allow for relative changes to occur – realignment of existing shares from different origins. They exhibit a property which we refer to in this paper as weak substitutability as opposed to strong substitutability, which allows absolute changes in market shares. In 2009, it has even been reported that in the beginning of the grain marketing year 2008/09 the South Korean livestock industry replaced imports of Corn from the US entirely by imports of wheat from Ukraine (AgriMarket 2009). The concept of strong substitutability seems thus even applicable beyond crop species for a proper description of international agricultural commodity markets.

Both mentioned examples concern products which are, first off, shipped in bulk and, secondly, intended for further processing rather than final consumption. While we tend to agree with the hypothesis of Sarker and Surry (2006) where final consumer goods are concerned, we argue that the assumption of product homogeneity is indispensable to obtain realistic results when modeling bulk commodities. Moreover, it is evident although the share of trade in agricultural consumer goods is apparently increasing that trade in agricultural bulk commodities is far from shrinking to insignificant volumes or even disappearing. On the contrary, above average population growth in low-income, food-deficit countries as well as prospects for large-scale industrial uses of agricultural bulk commodities mainly for the production of biofuels may even increase their share in future. Furthermore, although for consumers in Europe and Northern America food purchases of do usually take place in highly differentiated, processed products, we should not forget that a large share of consumers in developing countries as well as farmers all over the world and food processing companies buying in bulk are entirely responsive to the prices of agricultural commodities. We argue that the fact that markets for agri-bulk commodities exhibit dispersed trade matrices, which seems contradict the theory of homogeneity at first glance, is rather attributable heterogeneous costs of movements of goods.[2]

In this paper we, therefore, suggest an alternative theory for explaining the behavior of countries engaged in commodity trade with multiple potential partners. Maintaining the basic assumptions of the SPE, we add to it the hypotheses that bilateral transaction cost between countries are not uniform among all pairs of agents located in these countries and not constant over the whole range of the trade capacity of the countries.

The remainder of this paper is structured as follows: In the next section, we will review the properties of the SPE approach and of some alternative theories of spatial trade and *ex-ante* modeling approaches derived thereof. The proposition that all existent approaches have severe shortcomings in predicting the patterns of commodity trade is reinforced. In section 3, we introduce and explain in some detail the theory of a SPE with non-uniform and non-constant transaction costs. For the corresponding *ex-ante* model for scenario analysis, this is implemented by attaching an increasing transaction cost curve to each bilateral trade flow.[3] This procedure is, as we argue, in many regards analogue to the concept of positive mathematical programming (PMP) which has been developed by Howitt (1995) and others to calibrate normative supply models.

In section 4, we discuss crucial aspects of such a calibration procedure. In particular, we emphasize the need for an empirical base of the calibration term, and discuss a possi-

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2 As costs of movements of goods, we summarize freight costs, transaction costs and policy measures, in short everything that contributes to a price difference between the places of production and consumption.

3 In addition to constant per unit freight cost, tariffs and perhaps further trade policy measures.

ble framework in which to estimate the parameters of the calibrated SPE. In Section 5, we summarize our findings and draw conclusions.

2. Overview of existing theories of spatial trade and derived *ex-ante* modeling approaches

In this section, four theoretical approaches to explaining bilateral trading patterns of countries and derived simulation models are discussed. First, the SPE approach will be described and the points of critique mentioned in the previous section will be given sufficient room to be clarified in detail. Next, several alternative theoretical approaches to explain and model spatial trade, the Armington (1969) approach, the dispersed SPE approach as introduced by Harker (1988) and finally an approach developed by Ostrovsky (2005) are surveyed and discussed regarding their ability to replace the SPE as a theory of bilateral trade and a tool of *ex-ante* spatial trade analysis in homogeneous commodities. In section 2.5, an attempt by Paris *et al.*(2009) is reviewed who try to overcome some of the drawbacks of the original SPE model with a linear calibration technique.

2.1. Spatial Price Equilibrium

The SPE as developed by Samuelson (1952) if applied to countries as agents assumes that buyer countries source from the origin offering the lowest cif price, while selling countries sell to the destination offering the highest fob price. The corresponding *ex-ante* models are a generalization of the Koopmans – Hitchcock model of transport cost minimization in that their quantities of demand and supply in the model are price responsive whereas in the original Hitchcock-Koopmans model they are fixed. The latter problem has a linear objective function and constraints and can hence be solved with the simplex algorithm (Dantzig 1951). The first step to solve a SPE, a transportation problem with price responsive demand and supply functions, has been set by Enke (1951) who could show how traded quantities can be determined by using a simple electric circuit. Samuelson (1952) showed that a SPE can be cast as a maximization problem. In case of linear functions of supply and demand, which are the most simple conceivable form, this would imply a quadratic objective function. However, the problem could numerically not be solved until quadratic programming algorithms became available (Wolfe 1959) which were first applied to the problem by Takayama and Judge (1964). Model (1) shows the Net Social Payoff Function (NSP) to be maximized subject to appropriate, linear constraints as suggested by Samuelson (1952). The reader can easily verify that the objective function will be quadratic in case of linear supply and demand functions.

$$
\begin{aligned}
\text{Max } NSP = & \sum_j \int_0^{Dj} PD_j(u)\,\mathrm{d}u - \sum_i \int_0^{Si} PS_i(v)\,\mathrm{d}v \\
& - \sum_{ij} (tc_{ij} * X_{ij}) \\
\text{s.t.} \quad & \sum_j X_{ij} \le S_i \\
& \sum_i X_{ij} \ge D_j \\
X_{ij} \ge 0, \quad & S_i \ge 0, \quad D_j \ge 0,
\end{aligned}
\tag{1}
$$

with *i* being the set of producing regions, *j* the set of consuming regions, *S* being supply, *D* being demand, *PS* being the supply price, *PD* the demand price, tc_{ij} being the transportation cost[4] between regions *i* and *j*, and X_{ij} being the quantity traded between the two regions.

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4 This term can be expanded to include tariffs, export subsidies, transaction costs etc.

Despite its popularity and its wide application as a tool of positive economic analysis, the SPE model is essentially a normative model. When applying such a model to positive economic problems, one implicitly assumes that all agents in the model are fully informed, perfectly rational, utility maximizing individuals and that the model exhaustively captures all constraints that are faced by the real world agents whose behavior it intends to simulate. However, in virtually any case of economic optimization, not all real world constraints are known to modeler let alone possible to be integrated in the model. At the same time, the hypothesis of fully informed, perfectly rational, utility maximizing agents is a simplifying assumption. This leads to the unpleasant consequence that uncalibrated models are not accurate in reproducing the agents observed behavior.[5] In the practical example of the SPE trade model, this means that observed trade matrices cannot be reproduced perfectly by the model.

Besides this, the linearity of the Koopmans-Hitchcock model, which constitutes the trade module of the SPE model, is a second major source of inaccuracy. In the case of n^2 possible trade flows, only $2n-1$ will be strictly positive in a linear SPE model.[6] As a result, even if all real world costs of movement of goods were captured adequately, the model, by virtue of the linear formulation, would not be able to reproduce an observed trade matrix that contains more than these $2n-1$ trade flows. In particular, as Ostrovsky (2005) notes, in the case of two importing (A and B) and two exporting countries (C and D), if A exports the product in question to C and D, B cannot also export the product to both C

5 If an originally normative model is applied for positive analysis we do not refer to them as normative, but rather as uncalibrated.

6 Without further quantitative restrictions of trade such as tariff rate quotas (TRQ), that is.

and D. Furthermore, no cross-hauling is possible, i.e. if A exports to C, A cannot import from C at the same time. This argument extends to any form of circular trade.

Since the first applications of the SPE in applied economic research, many authors have hinted at these two sources of misspecifications and the resulting consequences (Batten and Westin 1989; Bröcker 1988; Harker 1988; Nolte 2008; Ostrovsky 2005; Roy 1990). Some of these authors (Batten and Westin 1989; Bröcker 1988) state that markets in certain strictly homogeneous commodities might indeed be properly described by the SPE model. However, there are probably no products in reality which exhibit the sharp trade pattern of merely *2n-1* positive trade flows to which the SPE is restricted, as is also suggested by the examples put forward by Ostrovsky (2005) who shows observed trade matrices of soybeans, live cattle, anthracite, natural gas and iron ore.

Of the authors mentioned above, Batten and Westin (1989) offer the most comprehensive critique of the SPE. Besides the factor of imperfect information hampering the performance of the SPE as a tool for positive economic analysis, they raise two further issues. These are first, the assumption of products being homogeneous and transport sensitive and second, the assumption of perfect competition. Both concerns can, however, be dealt with relatively easy, as the authors concede themselves. The problem of spatial heterogeneity can be accounted for by increasing the number of commodities by the number of regions. Such a model would exhibit a simulation behavior very similar to those relying on the Armington (1969) approach reviewed in the following subsection. While this is technically possible and would solve the problem of non-reproducibility, it would in many cases mean throwing out the baby with the bath water. As Heckelei and Britz

(2005) note, the objective of model design should be the development of a model that can reproduce an observed base situation and at the same time to exhibit a realistic simulation behavior. The former alone can also be achieved by simply introducing additional constraints. The introduction of spatial heterogeneity of products, however, would lead to less realistic simulation results of the SPE. The model must then not only ignore strong substitutability, but also gives rise to the potential of large spatial price disequilibria, especially in the case of longer term projections and/or significant trade policy changes.[7] The last issue the authors raise, the assumption of perfect competition, is not intrinsic to the SPE framework. As they point out themselves, various modifications of the model have been developed to account for various forms of imperfect competition (Harker 1986; Nelson and McCarl 1984).

However, despite the generally acknowledged poor performance of the SPE in reproducing observed trade flows, the model has the potential of being an excellent indicator of regional prices if the entire costs of the movement of goods are captured, as is discussed in section 1. Furthermore, it offers for problems of trade in homogeneous commodities the most realistic simulation behavior of all approaches surveyed in this section. For many research questions, these abilities are sufficient to perform an adequate analysis, which is one of the major reasons for its frequent application – despite the aforementioned drawbacks.

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7 In fact, producing such disequilibria as results of simulations is one of the major problem of models employing on the assumption of heterogeneity with regard to origin, which are surveyed in the following subsections.

In order to eliminate the misspecifications of the normative, linear SPE model, non-inclusion of unobservable real world constraints and the restriction to a maximum number of trade flows, Nolte (2008) suggests to calibrate the model by attaching a nonlinear cost term to each trade flow. This procedure is in many regards similar to Positive Mathematical Programming (PMP), a method developed to calibrate Linear Programming (LP) farm models. PMP has been developed and applied since the late 1980's, but is first formally described by Howitt (1995). LP farm models suffer from similar problems as the linear transport module of SPE models: Unobserved constraints cannot be accounted for and the number of strictly positive activities in the solution is bound by the number of binding, linearly independent constraints of the model. In subsection 2.5, a calibration procedure developed by Paris *et al.* (2009) which attaches linear cost terms to each trade flow is reviewed. However, as we will argue, the approach is due to the calibration term being linear able to eliminate merely the first of the identified two problems. The restriction to *2n-1* trade flows will still persist.

2.2. Armington Approach

The Armington (1969) assumption basically states that products are differentiated by the country of origin, which means, a product from, say, France is an imperfect substitute for the same product from, say, Japan. The author suggests implementation of this assumption in simulation models by means of a Constant Elasticity of Substitution (CES) utility function. The resulting import demand function has the following shape

$$X_{ij} = b_{ij}^{\sigma_i} X_i \left(\frac{P_{ij}}{P_i} \right)^{-\sigma_i} \qquad (2)$$

with X_{ij} being the import demand for good *i* from country *j*, b_{ij} being a constant, X_i being the total demand for good *i*, $\underline{P_{ij}}$ being the price for import of *i* from *j*, P_i being the average price of *i* and σ_i being the elasticity of substitution of *i* from different origins. The Armington assumption and its implementation as a CES utility function have found wide application in economic research and are used in virtually all existing Computable General Equilibrium models (CGE).

The consequences of the Armington assumption and its implementation using a CES function have been intensively debated in the past. Two of these drawbacks, which shall be discussed briefly below, are the most commonly debated and most relevant in the context of the paper. The first of these is sometimes referred to as the ‘stuck on zero trade’ problem (Abler 2006). Since the parameter b_{ij} is exogenous to the model depending on whether trade was or was not observed on a particular route in the base period, the routes on which trade in product *i* will take place under any scenario are determined *a priori*. By the same token, for those routes where trade was not observed in the base period, the model results are restricted to zero, since b_{ij} is zero. The second undesired property frequently discussed is the ‘small shares’ problem: if the trade on a particular route in the base period is small, b_{ij} will be small. As a consequence, even huge price changes will not trigger the imports of *i* from *j* to grow to significant volumes (Kuiper and van Tongeren 2006). As a consequence of trade flows not emerging or increasing sufficiently, large spatial price disequilibria can build up. This will in particular be the case when structural breaks in trade policies are modeled.

Ostrovsky (2005) argues the Armington assumption seems intuitively applicable to goods such as wine and cheese, but is hardly to justify for fungible commodities such as coal or natural gas. This argument can be extended to agricultural commodities with a fungible character, such as animal feed, inputs for biofuel production or other industrial applications based on various types of biomass as a feedstock.

2.3. Dispersed Spatial Price Equilibrium

Another approach to explaining and modeling spatial trade in bulk commodities trying to do away with the sharp predictions of the SPE model without going so far to adopt the Armington assumption is that of the Dispersed Spatial Price Equilibrium (DSPE) which is also discussed in the review paper by Batten end Westin (1989). It is derived and described in detail by Harker (1988) though first applications of the principle apparently date earlier. The concept of the DSPE is developed in the theoretical framework of the gravity model of trade. Bilateral trade flows in DSPE models follow the relation described in equation (3):

$$X_{ij} = a_i b_j S_i D_j \exp(\gamma[P_j - P_i - tc_{ij}]) \tag{3}$$

with a_i, b_j and γ being parameters estimated from observed trade data. The parameter γ is to interpreted as 'the marginal utility of profit' (Harker 1988). If it approaches infinity, the DSPE model converges to the SPE model.

For applications in simulation models, the reader will note that an additional parameter of the dimension i,j is required in equation (3) in order to calibrate exactly to observed trade. Adding such a parameter is problematic, though, in particular for cases where zero trade is observed in the base period. Ruling out the trivial cases where one of the countries has no production or consumption of the good in question, this additional parameter would need to be zero, leading directly to the 'stuck on zero trade' property of the Armington model. Instead inserting a parameter with a very small value leading to virtually zero trade, though, would introduce a moment of arbitrariness to the specification. Own experiments to estimate the parameters of the model with a stylized data set show in particular difficulties when trade flows are present for which the expression $[P_j - P_i - tc_{ij}]$ is negative and large, i.e. trade on this route would imply high monetary losses. In real world data sets, such situations are frequent and can emerge from measurement errors as well as from hidden or unknown subsidies or barriers to trade. Depending on the statistical criterion of estimation, in these cases either the additional i,j dimensioned parameter is extremely high or the parameters a_i and b_j are assigned rather high values.

Despite these drawbacks, the model – while being able to reproduce observed trade matrices – has the potential to overcome the 'small shares' property of the Armington model for bulk commodities, unless in the base situation significant parts of the world market are entirely isolated from each other. In spite of this, the approach has not been applied widely in applied economic research of international trade in the following decades.

2.4. Matching model with heterogeneous transportation costs

In a 2005 paper, Ostrovsky tests the SPE model and an Armington-based model for their ability to explain the spatial relationships in the global steel supply chain. For the reasons we discussed in sections 2.1 and 2.2 he finds that both models perform rather poor in reproducing observed trade matrices. The Armington model is even reported to lead to completely unrealistic predictions, which should not come as a surprise since the goods in question, steel, iron ore and scrap, hardly qualify as heterogeneous with regard to the country of origin.

As an alternative, the author introduces a new approach which he calls 'Matching Model with Heterogeneous Transportation Costs'. In this model, each country consists of small agents producing or demanding a discrete unit of iron ore or scrap at an agent specific price. That way, aggregating agents can lead to a representation of classical supply and demand functions for each country. Each of the producing agents is connected to each consuming agent by a pair-specific transportation cost. The average of these costs of agent pairs from two countries is chosen as the average transportation cost between the two countries and a pair specific, positive or negative shock is added. With these shocks distributed randomly, the Matching Model is found to reproduce observed trade matrices for the steel supply chain more precisely than the SPE or Armington model.

As we also suggest in sections 1 and 3, Ostrovsky's theory rests on the assumption that the reason for dispersion of trade flows of fungible commodities is not heterogeneity of the product in question, but rather heterogeneity of freight cost or, as we would prefer to put it, costs of movement of goods, which includes more components than freight alone.[8] To put the approach operational as a specification of existing agents in the steel supply chain or any other sector, a huge amount of data would be required. The number of actors in any sector is large and the number of bilateral costs increases quadratically with the number of agents. However, a detailed empirical specification may (and most likely will)

8 In fact, we assume it is not too simplifying to assume uniform freight costs over pairs of agents in two countries and rather see transaction costs as the major source of non-uniformity.

still lead to a result that does not reproduce observations. Thus some calibration work is still needed to put the approach operational as a positive model.

Reinforcing the relevance of our research agenda and its applicability beyond the agricultural sector, the author concludes that

> …[f]inding alternative ways of accommodating heterogeneity in bilateral transportation costs and determining relative strengths and weaknesses of different approaches are important areas for future research.

2.5. Calibrated SPE

As we argue in section 2.1 a calibration of the traditional SPE model by attaching a nonlinear cost term to each trade flow could solve the problem of non-reproducibility and the limitation of the number of trade flows in the solution. Recently, a calibration procedure for SPE models has been developed by Paris *et al.* (2009). The starting point of their argument is the observation that costs of movement of goods are measured with a high degree of imprecision, leading to distorted spatial price equilibria of the uncalibrated model. Their calibration procedure essentially follows the three steps of PMP as presented by Howitt (1995).[9] One major difference is that their calibration term can assume both positive and negative values whereas the calibration term in PMP is usually restricted to positive values. This reflects the fact that measurement errors of costs can, of course, occur in two directions. Since their objective is the achievement of an undistorted solution of the SPE rather than the reproduction of an observed trade matrix, their calibration term

9 This procedure is described in section 3 below with the help of equations (D) and (E).

is linear. As a consequence, they offer a solution to the first of the two sources of misspecification we identified in section 2.1, the inadequate representation of real costs of movement of goods. Recently, an analysis which applies the approach to the EU trade preferences for bananas has been published (Anania 2010). However, with the calibration by virtue of linear cost terms, implying the assumption of constant and uniform per unit costs of movement of goods, the second source of misspecification, cannot be removed and their model is still limited to a maximum number of *2n-1* trade flows. Their approach thus contributes to optimizing the parameterization of the SPE, but does not adapt the most basic structure of the model.

2.6. Conclusions from the literature review

This review of four theoretical approaches plus the calibration approach of Paris *et al.* (2009) to modeling bilateral trade flows in the preceding subsections illustrates that the issue of explaining dispersed matrices of flows of homogeneous goods and reproducing them with *ex-ante* models is recognized as relevant by agricultural and trade economists for more than four decades. Each of the approaches under review here, exhibits shortcomings in one or more crucial regards, though. The original ESTJ-SPE in the traditional formulation as well as in the calibrated version by Paris *et al.* (2009) are able to handle the products as homogeneous, but unable to produce a (unique) dispersed result. The Armington (1969) and DSPE approaches are able to produce dispersed trade matrices but have to release the homogeneity assumption. Of all approaches reviewed in this section, merely the one by Ostrovsky (2005) is able to deal with both requirements. The implementation of his approach in a simulation model, however, comes at the cost of either an unmanageable data demand or of having to define stylized agents for which no real world matches exist.

Consequently, a gap can be identified in applied agricultural trade analysis for a model that is first, able to simulate trade in homogeneous products, second, to produce a dispersed matrix of trade flows as a consequence of non-constant and non-uniform costs of movement of goods and, third, can be specified on the basis of a reasonable amount of accessible data. Part of the theoretical foundation of such a model can be inferred from Ostrovsky (2005), however, as we argued above, other sources of heterogeneity in cost of movements of good exist, which should be incorporated in the theory.

3. A SPE model with non-uniform and non-constant transaction costs

With this paper, we try to offer a possibility to fill this gap. As such, we suggest a theory of a SPE with non-uniform and non-constant (NUNC) transaction costs.[10] This theory of spatial trade in homogeneous or fungible commodities – agricultural and non-agricultural – adopts a large part of the basic assumptions of the ESTJ-SPE: Agents try to maximize their utility by selling to the destination offering the highest revenue and by buying from the lowest cost source. However, we release two other crucial assumptions. First, in our theory, each country or region is implicitly regarded as embodying a multitude of agents instead of being one agent. As has been suggested by Ostrovsky (2005), different pairs of such agents from two countries have different transaction costs of trad-

10 Doing so we leave with our theory the realm of neoclassical models of trade.

ing with each other. *Ceteris paribus*, the pair with the lowest bilateral transaction costs can be expected to be the first one establishing trade relations with each other within their respective capacities of production and consumption, followed by the pair with the second lowest transaction costs, etc. Second, we do away with the assumption that transaction cost are constant, i.e. a linear function of the quantity traded. Independent of whether we consider a country one agent or a multitude of agents, we assume that a marginal increase of shipped quantities to a particular partner country comes along with an increase in various forms of transaction costs, most notably of risk, e.g. that of collapsing prices from a sellers point of view or of a bad harvest from a buyers point of view, or of political instability in the partner regions from both partners point of view.[11] The relaxation of both assumptions independently as well as in combination will lead to increasing per unit transaction costs as a function of increasing quantities of trade between two countries.

Extending the traditional SPE by the NUNC assumption has the potential to explain the observed dispersion in international trade in fungible commodities. The corresponding *ex-ante* model offers a possibility to do away with the above mentioned shortcomings of the ESTJ-SPE model when trying to model trade patterns of agricultural and other fungible commodities. Technically, this is achieved by assigning a nonlinear cost term to each trade flow in addition to the observed freight costs. As stated in section 1, this approach is similar to PMP in many regards and involves analogue steps. Since the development and the first formal description of PMP in 1995, a huge body of literature has emerged

11 We acknowledge that other forms of transaction costs might decrease on a per unit base as a result of trading with only one instead of several partners.

discussing among others how to correctly specify a PMP supply model, which suggests that several methodological issues have to be taken into account when calibrating a SPE model, too. Nolte (2008) has suggested such a procedure already some time ago, but at that time a theoretical or empirical base was lacking. More precise, observations of freight costs of raw sugar on various routes did for instance, not support the hypothesis of increasing costs with increasing quantities of trade. This increase must thus stem from other sources. Interestingly, in PMP related literature, an argument analogue to ours has already been proposed by Heckelei (2002). The author notes that the presence of risk might be a justification for an increasing marginal cost curve in supply models. In the case of trade models, the presence of risk in the form of unpredictable, volatile prices in different possible destinations for a trader's shipment is obvious, also because trade does not take place instantaneously, but transport may require weeks or even months, in which either the revenue in the market one ships to might change, or if the terms of the contract are fixed in advance, the prices in other possible destinations might change, the implication of existing price risk being essentially the same. The following section discusses methodological and data aspects of calibrating a SPE model and where applicable picks up issues that have already been discussed in PMP related literature.

4. Aspects of Calibrating an SPE

4.1. The basic calibration concept

Calibrating a SPE is essentially calibrating its transport module which is identical to the linear Koopmans-Hitchcock transportation cost minimization problem posed as a LP problem. Consider model (4) with regional supply and demand quantities being given:

$$\begin{aligned} &\text{Min } Z = \sum_{\text{ij}} (tc_{ij} * X_{ij}) \\ &\text{s.t.} \qquad \sum_{j} X_{ij} \le S_i \\ &\qquad\qquad \sum_{i} X_{ij} \ge D_j \\ &X_{ij} \ge 0, \quad S_i \ge 0, \quad D_j \ge 0, \end{aligned} \tag{4}$$

This model can be calibrated by adding a nonlinear cost term to the objective function while maintaining the restrictions, as is done in model (5) using a quadratic cost function with two parameters, *d* and *q*:[12]

$$\text{Min } Z = \sum_{\text{ij}} (tc_{ij} + d_{ij} + q_{ij} * X_{ij}) * X_{ij} \tag{5}$$

We use here the quadratic function because it is a first order approximation of any other non-linear function that could be applicable. Other functional forms might thus be applicable as well. Following the three steps of PMP as described by Howitt (1995), first, a third restriction is introduced to model (4) limiting the trade flows to the observed values. Second, the calibration term $d_{ij} + q_{ij} * X_{ij}$ of (5) is determined such that it is equal to the

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12 For simplicity, it is assumed that no cross trade flow effects exist. The same restrictions as from (4) must be added to the model to be complete.

dual value of the additional restriction. Third, the calibrated model is solved and the observed trade matrix is reproduced.

4.2. Critical issues for calibration

As we will argue in the remainder of the section, there are a number of crucial aspects that need to be taken into account to make such a calibration a both economically and technically meaningful exercise.

Data availability

Data requirements to calibrate a SPE which is sufficiently disaggregated to perform meaningful global policy analyses are immense. Data is needed on supply, demand, stocks, regional prices, bilateral freight costs, applied bilateral trade policies, and finally bilateral trade flows. Data on supply, demand and stocks is usually available from various databases which are even publically accessible in many cases. Comprehensive global data on national or regional prices on the other hand are most probably not available for any commodity. The same is true for bilateral freight cost, which are however recorded for key routes in specific markets, for instance for sugar (ISO various years). Information on bilateral trade policies is available from ITC (2008). It requires detailed additional knowledge of the commodity market in question, though, to implement them correctly in a model. Data on bilateral trade flows between countries is also available from ITC (2007), but the quality is rather poor. Jansson and Heckelei (2009) note that even if data on regional prices and bilateral trade costs are available, they are likely to be inconsistent. In their article, the authors develop a method to estimate these two parameters under the assumption of a dataset which is complete, but shows inconsistencies between prices and trade costs.[13] In most cases where the modeler deals with real world problems, there will no complete dataset be available, though, and other solutions have to be found to deal with lacking, incomplete and unreliable data.

From Ostrovsky's (2005) argument illustrated in section 2.1 it can be directly inferred that in case of observed cross-hauling or any other form of circular trade, at least one of the calibrated cost terms on the involved routes needs to be both negative and absolutely higher than the tariff and freight costs observed on that route. Furthermore, the mere observation that trade occurs on routes which are not selected by the SPE algorithm requires that a negative calibration term will be a very common outcome of the calibration procedure, no matter which method is chosen to determine regional prices and freight costs for which no observations exist. Hence, an economic theoretical explanation needs to be offered for the – sometimes very large – negative values of the calibration terms.

Nonlinearity of the calibration term

In the introduction, we argue that non-uniform transaction cost over pairs of agents in two countries as well as non-constant transaction cost over the entire capacity of a countries foreign trade in one commodity lead to an increasing transaction cost curve. This implying a nonlinear calibration term requires a reformulation of the traditional, linear SPE model into a nonlinear model. The calibration approach developed by Paris *et al.*

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13 Jansson and Heckelei do not model trade polices explicitly. The trade costs they use can be interpreted as combined freight costs and policy measures. They refer to their estimation procedure as calibration as well, although what they do is fundamentally different from the calibration procedure which this section is about. The purpose of the authors' calibration exercise is to estimate a consistent set of regional prices and bilateral freight cost based on existent but inconsistent observations on both. Our calibration alters the fundamental structure of the model from linear to nonlinear.

(2009), a SPE calibrated with a linear cost term leaves the structure of the SPE unaltered and is thus not able to reproduce an observed matrix of trade flows since the model is still linear and thus constrained to a solution of *2n-1* trade flows, which is less than is observed in most markets, even those for homogeneous products. Consequently, to calibrate a SPE in order to reproduce observed trade matrices, at least a subset of the calibration terms need to be nonlinear. Furthermore, in order to produce a convex model which will result in one unique solution rather than multiple local optima, it is necessary that the nonlinear calibration term be increasing in the quantity traded. The economic rationale for such a nonlinear and increasing cost function is debated in the theoretical considerations in section 3.

Estimation of the calibration term

As many authors note (see Heckelei and Britz (2005) and the literature cited there), there is an infinite number of combinations of the parameters *d* and *q* yielding a calibration term equal to the dual value from the second step of PMP, all of which will result in a perfectly calibrated model. The simulation behavior of the model is thus arbitrary. In order to perform meaningful economic analyses with the calibrated model, it is therefore essential to as much theoretical and empirical information as possible is processed in determining the functional form and its parameters (*d* and *q* in the example).

Non-observed trade flows

A further question to be addressed is which value of the calibration term to assign to trade flows which are not observed in the base period. Any calibration term which raises the costs of imports beyond the market price for this particular trade flow will calibrate the model. An analogue problem has also been recognized and addressed for PMP supply models (for instance by Júdez et al. 2008). Production activities not observed in the base period cannot be assigned a calibration term by the standard PMP procedure. In practice they are therefore often fixed to zero, which is of course very restrictive and undesirable in the context of potential but not observed trade flows. A solution can be to include observations from multiple periods in the determination of the calibration terms which increases the chance of a potentially economic reasonable trade flow or activity being observed in at least one of the periods.

Use of multiple observations for the estimation of the calibration term

Heckelei and Wolff (2003) illustrate that in the case of supply models which are calibrated with PMP in its original form, a fundamental inconsistency is given rise to which in particular makes it problematic to include multiple observations in the estimation of the parameters. Consider model (6) below which represents in matrix notation the model built for the first phase of traditional PMP:

$$
\begin{aligned}
\max_{x} \quad & Z = \mathbf{p'x} - \mathbf{c'x} & & \\
\text{s.t.} \quad & A\mathbf{x} \leq \mathbf{b} & & [\boldsymbol{\lambda}] \\
& \mathbf{x} \leq (\mathbf{x^0} + e) & & [\boldsymbol{\rho}] \\
& \mathbf{x} \geq \mathbf{0} & &
\end{aligned}
\qquad (6)
$$

From the resulting first order conditions, it can be shown that the shadow prices of limiting resources are dependant only on the gross margins and coefficients of resource requirements of the marginal activities (indexed with the superscript ^{m}), i.e. those which are bound by the resource constraints rather than the calibration constraints:

$$\boldsymbol{\lambda} = (\mathbf{A^{m\prime}})^{-1} (\mathbf{p^{m}} - \mathbf{c^{m}}) \tag{7}$$

This leads to the consequence that the shadow prices **λ** are assigned the highest possible values and to an inconsistency with the calibrated, quadratic model (8):

$$\begin{aligned} \max_{x} \quad & Z = \mathbf{p'x} - \mathbf{d'x} - \tfrac{1}{2}\,\mathbf{x'Qx} \\ \text{s.t.} \quad & A\mathbf{x} \le \mathbf{b} \qquad [\boldsymbol{\lambda}] \\ & \mathbf{x} \ge \mathbf{0} \end{aligned} \tag{8}$$

and the shadow prices which can be deducted from its first order conditions:

$$\boldsymbol{\lambda} = (\mathbf{AQ^{-1}A'})^{-1} (\mathbf{AQ^{-1}(p - d) - b}) \tag{9}$$

Using first order conditions as estimation equations

To avoid this inconsistency and the arbitrary assignment of shadow prices, the authors suggest to estimate shadow prices of resources and the coefficients of the model simultaneously using the first order conditions of the model which is considered the true data generating process or a acceptable approximation thereof as estimation equations:

$$\begin{aligned} \min_{d,Q} \quad & H(\mathbf{e}) \\ \text{s.t.} \quad & \mathbf{p - d - Q(x^{0} - e) - A'\boldsymbol{\lambda} = 0} \\ & \mathbf{b - A\,(x^{0} - e) = 0} \end{aligned} \tag{10}$$

with H being a statistical criterion, for instance generalized least squares or maximum entropy.

It is not entirely possible to transfer this discussion to the calibration of LP transport models as will be shown in the following. Consider the following transport model (11):

$$\min_{x} \quad Z = \mathbf{tc'x}$$

$$\text{s.t.} \quad \mathbf{Ux} \le \mathbf{s} \qquad [\mathbf{ps}]$$

$$\mathbf{d} \le \mathbf{Vx} \qquad [\mathbf{pd}] \tag{11}$$

$$\mathbf{x} \ge \mathbf{0}$$

where

Z = objective function value

tc = (i*j x 1) vector of transport costs

x = (i*j x 1) vector of trade flows

U = (i x i*j) matrix of coefficients (1 or 0)

s = (i x 1) vector of local supply in region i

ps = (i x 1) vector of local producer prices in region i

V = (j x i*j) matrix of coefficients (1 or 0)

d = (j x 1) vector of local demand in region j

pd = (j x 1) vector of local consumer prices in region j

i = number of producing regions

j = number of consuming regions

i*j = number of possible trade flows

The two restrictions can be combined by merging matrices **U** and **V,** vectors **s** and **d** and vectors **ps** and **pd** to

$$\mathbf{W} = \begin{bmatrix} \mathbf{U} \\ -\mathbf{V} \end{bmatrix}$$

$$\mathbf{b} = \begin{bmatrix} \mathbf{s} \\ -\mathbf{d} \end{bmatrix} \tag{12}$$

$$\mathbf{p} = \begin{bmatrix} \mathbf{ps} \\ \mathbf{pd} \end{bmatrix}$$

and model (11) can be recast such that its shape is, apart from being a minimization rather than a maximization problem, identical to a LP supply model (13).

$$\begin{array}{lll} \min\limits_{x} & Z = \mathbf{tc'x} & \\ \text{s.t.} & \mathbf{Wx} \leq \mathbf{b} & [\mathbf{p}] \\ & \mathbf{x} \geq \mathbf{0} & \end{array} \tag{13}$$

Adding calibration constraints to model (13) will yield a model basically identical to model (6) above constituting the first phase of traditional PMP.

$$\begin{array}{lll} \min\limits_{x} & Z = \mathbf{tc'x} & \\ \text{s.t.} & \mathbf{Wx} \leq \mathbf{b} & [\mathbf{p}] \\ & \mathbf{x} \leq \mathbf{x^0} + \mathbf{e} & [\boldsymbol{\rho}] \\ & \mathbf{x} \geq \mathbf{0} & \end{array} \tag{14}$$

The calibrated model analogue to (8) is

$$\begin{array}{lll} \min\limits_{x} & Z = \mathbf{tc'x} + \mathbf{d'x} + \mathbf{x'Qx} & \\ \text{s.t.} & \mathbf{Wx} \leq \mathbf{b} & [\mathbf{p}] \\ & \mathbf{x} \geq \mathbf{0} & \end{array} \tag{15}$$

The first order conditions of (15) will, analogue to (8), lead to the lowest possible value for the lowest shadow price, i.e. zero. As in (8), the remaining shadow prices depend on each other and while they are biased upwards in (8) they are generally though not necessarily biased downwards when derived from (15). Due to the structure of the coefficient matrix **W**, a full mathematical proof of the inconsistency of the shadow prices **p** calculated on the basis of both models as is demonstrated for supply models in equations (7) to (9) is not possible. In particular, the expression $\mathbf{WQ^{-1}W'}$, corresponding to $\mathbf{AQ^{-1}A'}$ in equation (9), is a singular matrix and thus no inverse can be formed. However, the lowest shadow price of the model being zero alone, which implies that the product in this region is available for free, is a sufficient argument for not applying the first step of traditional PMP as estimation procedure for shadow prices.

Further advantages of the complementarity formulation

A further argument for rather choosing the first order conditions as estimation equations, as suggested by Heckelei and Wolff (2003) shall be elaborated in the following. Consider trade policies to be introduced in model (14). A specific i.e. per unit tariff can be introduced without any difficulties, since mathematically it is identical to a – per unit – transport cost. An *ad valorem* tariff, however, is calculated as a fraction of the cif price of the product to be imported. Technically, this would require an objective function containing the shadow prices of the constraints. It can be shown that the construction of such a model is impossible, the model is termed non-integrable (Rutherford 1995) and the only way to solve it would be an iterative procedure in which the effective value of an *ad valorem* tariff is calculated based on shadow prices from the previous model solution until the solution converges. This problem can be solved by using the first order conditions for estimation of the parameters as well as for simulation with the final model. Consider model (11). The first order conditions are

$$\mathbf{tc + U'ps - V'pd \geq 0} \qquad \perp \mathbf{x \geq 0} \qquad (16)$$

plus the constraints of model (11), or in common algebraic notation, which casts the problem more intuitively,

$$ps_i + tc_{ij} - pd_j \geq 0 \qquad \perp x_{ij} \geq 0 \qquad (17)$$

in which an *ad valorem* tariff (tar_{ij}) can easily be integrated.

$$(ps_i + tc_{ij}) * (1+ tar_{ij}) - pd_j \geq 0 \qquad \perp x_{ij} \geq 0 \qquad (18)$$

Estimation equations

The estimation equations of such a model in common mathematical notation, including besides *ad valorem* tariffs also specific duties (sd_{ij}), tariff rate quotas (trq_{ij}), and export subsidies (exs_{ij}) can be[14]

$$\min_{d,\,q} \quad H(\boldsymbol{\varepsilon}^1, \boldsymbol{\varepsilon}^2, \boldsymbol{\varepsilon}^3)$$

$$([ps_i + \varepsilon^1_i]\ tc_{ij} + exs_{ij} + [pq_{ij} + \varepsilon^2_{ij}]) * (1+ tar_{ij}) + sd_{ij} + d_{ij} + q_{ij} * x_{ij} - [pd_j + \varepsilon^3_j] \geq 0 \qquad \perp x_{ij} \geq 0$$

$$\sum_j x_{ij} \leq s_i \qquad \perp ps_i \geq 0 \qquad (19)$$

$$d_j \leq \sum_i x_{ij} \qquad \perp pd_j \geq 0$$

$$x_{ij} \leq trq_{ij} \qquad \perp pq_{ij} \geq 0$$

with *H* being a statistical criterion. This framework is furthermore capable of including more than one observation, i.e. observations from multiple periods. Note that in order to do so, an additional error term of the dimension *i*,*j*,*t*, t standing for the period, needs to be

[14] For simplicity, we assume that off-diagonal elements of the matrix Q are zero.

added to the estimation equation. Otherwise the problem is likely to have no feasible solution.

Solution of bi-level programs

Heckelei and Britz (2005) hint at another issue arising in this context, which is finding a solution for the class of bi-level programs consisting of an outer problem, in our case the minimization of *H*, and an inner problem, in our case to determine which of the inequalities in (19) will or will not hold with strict equality, the latter implying their corresponding dual variables being zero. Numerically, this has the potential of confronting a standard optimization solver with severe problems of finding a solution. In the case of calibrating a transport model to observed trade flows this seems, however, to be less of a problem. Out of the four inequalities in (19) the first holds by virtue of the very problem for each observed trade flow and does not for those which are not observed. The second and the third, i.e. the regional supply balances can be assumed to always hold by economic rationale. And also the restrictiveness of fourth inequality can *a priori* be determined by simply assuming that if the observed trade in this route is larger than or equal to the TRQ.[15] As a result the inner problem disappears and the minimization of *H* remains the only problem to be solved.

Information from the uncalibrated model as complement to observations

The best practical solution for the estimation of the calibration terms is highly dependent on the availability of data. Recall that data on produced, consumed and traded quanti-

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15 The current notation does, for reasons of simplicity, not allow above quota imports to take place. This problem can be addressed, by adding to the two dimensions of exporter and importer a third dimension to each trade flow, which is the scheme under which it takes place (Nolte et al. 2010).

ties is assumed to be available. What is left and a major issue in determining which approach to choose for the estimation is the vector of regional prices. In model (19), prior information on all regional prices is included. In most practical cases, such data will, however, not be available. Experiments of an estimation with only one regional price (the world market price) provided as prior information and a statistical criterion composed of error terms of the dimension *i,j,t* (i.e. one error term per price transmission equation) to be minimized led to extremely implausible results for the remaining regional prices. As has been mentioned, SPE models perform quite well in reproducing local prices if costs of movement are captured comprehensively. This provides a good though not undisputable argument for using regional prices produced by a normative, uncalibrated SPE as priors for the estimation.

The same argument can be drawn upon for a solution to the problem of how to calibrate non observed trade flows. Since the costs of movement which are observed or extracted from literature can be regarded an unbiased expected value of the true costs of movement, a pragmatic solution can be to adopt this expected value for simulations unless better information is available. This is certainly a more reasonable solution than fixing non-observed trade flows to zero. Finally, the argument of the SPE as a good indicator of regional prices suggests that the effect of the parameter q which on the total costs of movement must be rather limited. Recall that this parameter accounts for increasing costs with increasing volumes of trade as a result of risk considerations of the involved agents. If this parameter were large, it had the potential to lead to large spatial price disequilibria, which for homogeneous commodities can usually not be observed in reality.

Summary

In summary, in order to perform a calibration of an ESTJ SPE which can reproduce a matrix of observed trade flows, several requirements need to be fulfilled and various methodological problems need to be addressed by the modeler. In order to obtain a strictly convex model, the calibration terms need to be nonlinear and increasing. Furthermore, a sizable share of the cost terms to be attached will have to be negative. For both phenomena, an economic explanation should be offered. In order to avoid arbitrary simulation behavior of the final model, the attached cost terms should be empirically well founded. Moreover, such an estimation should have the flexibility to include multiple observations without producing inconsistencies. Finally, the problem of data availability needs to be addressed in virtually any practical case of application of the approach. This relates to data on quantities, in particular trade flows, for which the available data is in many cases rather poor and furthermore inconsistent with data of net exports implied by supply, demand and stock holding data. In second instance, this relates to data on regional prices which are necessary as prior information during the estimation of the cost terms.

5. Summary and Conclusion

The theory of SPE with the corresponding ESTJ-SPE model is hitherto basically the only approach of spatial trade analysis which employs the assumption of homogeneous goods. As we argue and demonstrate with examples from the recent past, this property is essential when modeling trade in fungible agricultural and non-agricultural commodities. Moreover, although the share of agricultural trade in differentiated high value added products in total agricultural trade has been steadily increasing, in particular in value terms, the share of fungible commodities in total agricultural trade is still significant and has the potential to grow in future with industrial applications of biomass being on the rise.

The SPE has, however, one important shortcoming which is its quasi-normative nature. It is mimicking coordinated optimizing behavior of an aggregate of independent agents subject to linear cost functions and constraints. This leads to predictions which do not reflect observed trade patterns and due to the linearity to a necessary restriction of the total number of predicted trade flows which is usually far below the observed number of trade flows. We argue that the observed dispersion of trade flows does not stem from heterogeneity in products, nor from increasing freight costs, but rather from non-uniform transaction costs over pairs of agents and non-constant per unit transaction costs over any range of quantities. Together with freight costs and policy measures, transaction costs account for the total costs of movement of goods.

After review of alternative approaches and their shortcomings in order to constitute a genuine alternative to the generic SPE, we establish three requirements for such an alternative. First, the homogeneity assumption must not be released, second, the theory and the model must be able to explain and reproduce the observed dispersion in trade flows and third, it must be possible to specify the model with a reasonable amount of data. To that end, we extend the SPE with the NUNC assumption which provides an economic justification for a elements of nonlinearity in the model. The assumption basically states that agents active in international trade, buyers and sellers, whose aggregate behavior represents that of countries, are willing to accept non-optimal buying and selling prices as a result of emerging transaction costs. They might e.g. want to reduce search costs by trading with previous trade partners, by stopping short of collection full information on costs and revenues and they might want to reduce their price risk by trading with partners from multiple regions rather than the one which offers the most economic conditions at a particular point in time. For simulation analyses, we suggest to calibrate the SPE by attaching a nonlinear cost term representing these transaction costs aggregated over agents and quantities and discuss several aspects of such a calibration, in particular a consistent estimation of the parameters of the calibration term on the basis of multiple observations.

Technically, the same result, i.e. a model which satisfies the three requirements stated above, could have been achieved by introducing a transport sector in the model which operates at increasing marginal costs on each route. However, this assumption could not be confirmed by data on freight costs for raw sugar, which are comparably well documented.

In the introduction we state an example of the South Korean market for feed grains, where corn from the US was entirely substituted for by wheat from Ukraine. Although technically and theoretically, the problem is very similar to strong substitutability of the same product from different countries of origin, it can not be tackled by a theory of foreign trade and had rather to be tackled by an alternative model of demand.

The major advantages of spatial trade models as opposed to net trade models are the possibility to take the location of countries on the one hand and discriminatory or preferential trade policies on the other hand into account. From an economic point of view, it is generally accepted that the determinant of preferential trade in homogeneous products are preferential margins including quota rents. These can, however, explained already in a satisfactory manner by the traditional SPE approach, as we would argue. In the recent past, the analysis of such scenarios was the predominant purpose of application of ESTJ-SPE models as for instance in the studies by Anania (2010) or Nolte *et al.* (2010)

The merits of the calibrated NUNC-SPE approach are thus rather to be found in the first mentioned strength of spatial trade models, the explicit simulation of the location of model regions. Consequently, the adequate fields of applications of the calibrated SPE are less preferential trade arrangements, but rather general spatial questions of trade analysis. Possible research questions can be derived in the context of the two examples discussed in the introduction. For instance, how will a bumper crop of sugar in India affect the import composition of countries in the Indian Ocean and worldwide? What would be the effects of an overall increase in ocean freight rates? How will regional prices be affected? How will a temporary shortage of corn in North America and a good harvest of wheat in Eastern Europe affect the composition of feed ratios in intensive livestock production in different locations in the world? The emerging large-scale use of agricultural bulk commodities for energy production and other industrial applications in certain parts of the world will add a further element of variability to the spatial dimension of global trade in these goods and provide an ample and potentially fruitful field of application of the calibrated SPE approach.

The NUNC assumption which we introduce in this paper as a theoretical foundation of a calibrated SPE itself can hardly be tested empirically.[16] The amount of data to be collected is only one of the obstacles in this regard. However, as the competing ones surveyed in the literature review, the hypothesis can be tested implicitly by constructing a model based on the respective theory and finding a parameterization of such a model which would ideally fit the observed data better than competing models.

16 As are the implicit assumption of Samuelson's theory (no transaction costs or uniform and constant ones) or the Armington assumption.

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