A disaggregate stochastic freight transport model for Sweden

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1. Introduction

The main feature of recent national freight transport models in Europe is the incorporation of a logistic component (module) in the traditional freight demand-modelling framework (de Jong et al. 2013). Logistics decisions of firms are incorporated in the modelling process often based on shipment size optimization theory.[1] According to this theory, firms are assumed to minimize total annual logistics costs by trading-off inventory holding costs, order costs and transport costs. The logistics module estimates frequency/shipment size choice and transport chain choice (i.e. transport mode choices and use of trans-shipment)[2] based on a cost minimization model where firms are assumed to minimize annual total logistics costs.

Such logistics modules have been developed for the national freight models of Norway, Sweden (SAMGODS model)[3], Denmark and Flanders (see Ben-Akiva and de Jong, 2013), within the overall framework of the aggregate-disaggregate-aggregate (ADA) freight transport model.[4] The current logistic modules in these countries, however, lack two main elements. First, they do not account for the main determinants of shipment size and transport chain choices other than cost, i.e. decisions are mainly based on cost considerations (and to some extent on factors such as access to road and rail and value densities). Second, these models are deterministic and lack a stochastic component[5]. A deterministic model has a weak empirical foundation: the way transport agents (i.e. shippers, forwarders and carriers) behave in the model is not based on observed behavioural data but on the assumption that they will choose the shipment size and transport chain that has minimum costs, with some model calibration at a highly aggregate level. To improve the predictions of current models and allow richer and more realistic policy analyses, logistics decisions should be modeled taking into account these two elements.

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[1] See Chow et al. (2010) for a comprehensive review of freight forecast models elsewhere.

[2] A transport chain is defined here as a series of modes that are all used to transport a shipment from the sender to the receiver (e.g. road-sea-road).

[3] Section 3.1 gives a brief overview of the national freight transport model for Sweden, SAMGODS. At the core of this model is the ADA model framework first suggested by de Jong and Ben-Akiva (2007). It starts with an aggregate model for the determination of flows of goods between production (P) zones and consumption (C) zones. After this comes a disaggregate "logistics" model, that based on PC flows produces OD (origin-destination) flows for the network assignment which is the third phase (aggregate again). For example, A PC flow that uses the transport chain road-sea-road between the production and consumption locations contributes to three OD flows (one for each of the modes in the chain).

[4] Moreover, models for shipment size and mode choice have been developed based on the French ECHO dataset at the shipment level (Combes, 2010).

[5] A partial exception is that the Danish national freight model contains a module for the choice of mode to cross the Fehmarn Belt screenline that uses a random utility model estimated on disaggregate data (including stated preference SP surveys in the Fehmarn Belt corridor). Other transport chains, however, for example in Denmark, are handled by a deterministic logistics model (Ben-Akiva and de Jong, 2013, section 4.6).

The main objective of this paper is estimating and implementing a disaggregate stochastic (logit-type) logistics model for Sweden, which overcomes the aforementioned shortcomings. Stochastic models of mode (or transport chain) and shipment size choice have been estimated before (e.g. McFadden et al. 1985; Inabe and Wallace, 1989; Windisch et al., 2010; Combes, 2010; Lloret-Batlle and Combes, 2013; Combes and Tavasszy, 2016; Caspersen et al., 2016). Their estimation is, however, for all commodity types together, or for a few selected commodities, whereas we have estimated models for many different commodity types. A systematic comparison between stochastic and deterministic models in an implementation context (e.g. in terms of elasticities calculated from runs with the actually used models) is also usually missing.[6] While estimation and implementation of aggregate stochastic models were done before, in the context of a national freight transport forecasting model (e.g. Bovenkerk, 2005; Tavasszy et al., 1998; Rich et al, 2009; Jourquin et al., 2014), we think this paper is the first implementation, in the framework of a national model, of a ***disaggregate*** freight transport chain and shipment size model estimated on data containing observed choices for individual shipments, certainly in Europe.

As a result of adding this stochastic component in the logistics model, the response functions (now expressed in the form of probabilities) become smooth instead of lumped at 0 and 1 as in the deterministic model. This in turn addresses the problem of “overshooting” that is prevalent in a deterministic model when testing different policies.

Overshooting happens when the relevant part of the logistics costs function is rather flat and a small change in logistics costs can lead to a shift to a completely different optimum shipment size and transport chain (Abate et al. 2014). On the other hand, there could also be “sticky” choices in a deterministic (all-or-nothing) model when one alternative is clearly cheaper than the other alternatives. Improving the other alternatives will then not lead to any change in market shares until one of these other alternatives becomes the cheapest and then the deterministic choice is suddenly completely altered. In this paper, we investigate the elasticities for changes in transport costs of different sign and size for both the deterministic and the disaggregate stochastic model, calculated in both cases from the implemented model in the framework of the Swedish national freight model. This allows us to analyze the relation between the elasticity and the magnitude of

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[6] We are not comparing different network assignment techniques in this paper (both methods rely on the same skims from unimodal networks which yield input variables for the allocation to transport chain and shipment size that is being studied here).

the cost change, whether the deterministic model indeed suffers from the problems mentioned and whether the stochastic model improves this.

The research gaps that we are addressing in this paper therefore are the following:

- Estimation results for transport disaggregate transport chain and shipment size choice models for a wide range of different commodity types;
- Implementation of disaggregate logistics models in the context of a national freight model system;
- An empirical investigation into the differences between implemented stochastic and deterministic models: do stochastic models lead to smaller sensitivities for time and cost changes?

The empirical analysis in this paper involved two steps. As a first step, we estimated econometric models that describe the determinants of transport chains and shipment size choices. We used the 2004/2005 Swedish Commodity Flow Survey (CFS)[7] and inputs from the SAMGODS model for estimation of multinomial logit models (MNL) for 16 different commodity groups. Note that by their very nature the MNL models are probabilistic models because they include a stochastic component to account for the influence of omitted factors (there is no other randomness in the stochastic models in this paper than this component; estimating and applying the disaggregate model does not involve draws from some statistical distribution). The main results from estimation of the MNL models show that variables such as transport cost and time, having access to rail or quay at origin and distance are important determinants of shippers' mode and shipment size choices.

As a second step, based on the MNL estimation results, we implemented (i.e. program in the application context) the disaggregate stochastic logistics model for two commodity groups, metal products and chemical products within the framework of SAMGODS. Using this model, we compared transport cost and time elasticities for tonne-km between the stochastic and deterministic models for the two commodities. In earlier applications of the deterministic model we have seen examples of overshooting and we expect that the elasticities from the stochastic model will be smaller (in absolute levels), showing less tendency towards overshooting.

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[7] See http://www.trafikverket.se/contentassets/23a269d514d24920ad445881d724811f/filer/vfu_2004_2005.pdf for details.

The remaining part of this paper is organized as follows. Section 2 presents the econometric model set up and results from estimation; Section 3 describes the stochastic model setup based on the inputs from Section 2; Section 4 compares model outputs from the stochastic and deterministic models; finally, Section 5 presents our main conclusions and suggestions for future work.

2. Econometric framework

Econometric studies of freight mode/vehicle choice are based on the key insight that mode/vehicle/cargo unit choice entails simultaneous decisions on how much to ship (see, for example, Abate and de Jong, 2014; Johnson and de Jong, 2011; Holguin-Veras, 2002; Abdelwahab and Sargious, 1992; Inaba and Wallace, 1989; McFadden et al., 1985). Large shipment sizes usually coincide with higher market shares for non-road transport, whereas there is a high correlation between road transport and small shipment sizes. Such a correlation calls for a joint econometric model. Abate et al. (2014) tested two types of joint econometric models, namely: a discrete-discrete (DD) model where the dependent variable is a discrete combination of shipment size categories and mode choice alternatives, and a discrete-continuous (DC) model which treats transport mode chain choice as a discrete variable and shipment sizes as continuous variable. Although DC models were found to be theoretically sound, given the size of the CFS data and the number of commodity groups involved, a pragmatic alternative is a DD model. In this paper, we estimate a DD which is specified as follows:

$$U_i = \beta_1 TC_i + \beta_2 TT_i + \beta_3 VD_i + \theta X_i + \varepsilon_i \qquad (1)$$

Where U_i is the utility derived from choosing a discrete combination of transport chain and a shipment size category i, the βs and θ are parameters to be estimated and ε_i is an error term.[9] Since U_i is a joint variable, the model setup allows for simultaneous consideration of transport chain and shipment size decisions. The main explanatory variables are transport cost (TC), transport time (TT) and value density (VD). X includes other control variables such as infrastructure access indicators, shipment type (domestic/international) indicators and alternative-specific constants.

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[9] In this study, as in most previous studies, we consider the weight of shipment size as an endogenous variable. However, we note that shipment volume (in m^3) is also an important factor, which shippers consider jointly with mode choice decisions. We cannot model shipment volume because our data set, the Swedish CFS, does not contain this information.

We estimate Equation 1 using a multinomial Logit model (MNL). A study by Windisch et al. (2010), who also used the 2004/5 Swedish CFS to estimate DD models, applied a Nested Logit (NL) models, found that there is more substitution between shipment size classes than between transport chain types. However, unlike our approach of commodity by commodity estimation, they estimate their NL model using all commodity groups in the CFS together. We tested the coefficient of the logsum coefficient to check which model is appropriate for each commodity group in our sample. We set up the NL model by classifying nests based on the main mode used, thus our classification assumes that transport chains defined by alternatives using the same main mode have the same nest coefficients. We found out that for most commodity groups (including metal and chemical products which we study in detail in the paper), the nest coefficient is not significantly different from one, implying zero correlation among shipment size categories in the nest, so the NL model collapses to the MNL model.[10]

2.1. Data

The main data source for this paper is the 2004/2005 Swedish Commodity Flow Survey (CFS). The data has 2,986,259 records. Each record is a shipment to/from a company in Sweden, with information on origin, destination, modes, weight and value of the shipment, sector of the sending firm, commodity type, access to rail tracks and quays, etc.[11] From this we selected a file of around 2,897,010 outgoing shipments (domestic transport and export, no import) for which we have complete information on all the endogenous and exogenous variables.

Although the CFS data is extensive, it does not contain information on transport costs and transport time variables. Given the importance of these variables in mode/shipment size choice analysis, the existing logistic module of the deterministic model was used to generate them for each shipment in the CFS. They were generated both for the chosen mode-shipment alternatives in the CFS and for potential non-chosen alternatives tailored to each shipper based on the transport network of the origin and destination of their shipment.

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[10] We note that there could be correlations between alternatives, especially given that there are alternatives that have a transport chain (or a shipment size) in common. More complicated nesting structures can be tried in mixed logit and multivariate probit models, but these model types have very long run times, especially on large data sets as we have here.

[11] In the CFS a shipment is defined as a unique delivery of goods with the same commodity code to/from the local unit or to/from a particular recipient/supplier (SIKA, 2004).

The CFS classifies transport mode chains to chains inside Sweden and chains outside Sweden. In domestic shipments, trucking accounts for the overwhelming majority of the shipment frequency (95.79%), followed by chains which involve waterborne transport modes (a ship vessel and ferry).[12] The high share of trucking is also evident in its percentage share in weight and value in domestic freight transport. For international shipments, vessel (maritime) transport accounts for the highest share both in shipment weight and value.

To see the distribution of shipment sizes we classified the weight variable in the CFS into 16 categories[13], as shown in Table 1. A quarter of the total shipments fall in the first category (0-50 kg). The prevalence of small shipments reflects the dominance of trucking which is usually preferred for its flexibility and reliability. Categories 10 and 11, ranging from 35 to 45 tonnes (well within a full truckload range), account for 23.71 %, again showing the dominant role of trucking.[14]

Figure 1 presents the cumulative density distribution of shipment weight for metal products and chemical products and for all commodities in the CFS. Shipments weighing 10 tonnes or less account for about 90% of the shipments for the two product groups. This distribution is somewhat different from what is observed for all commodities which also have concentration of larger shipment sizes.

There are 24 commodity groups in the CFS. In this paper, however, we found it to be more instructive to analyze selected commodities than all commodities identified in the CFS. This is due to the dominance of trucking for most shipments. In fact, for ten commodity groups the share of trucking is more than 98 %. Clearly, there is little to learn about the determinants of mode choice decisions of shippers when there is such overwhelming dominance of one mode of transport. For the remaining 16 commodity groups, including metal products and chemical products for which we implemented a stochastic module, there is relatively less dominance of trucking. The road share, measured in tonne-km, is about 38% for all commodities and differs a lot between the commodities (See Table 5 in: Vierth et al., 2014). The share is 17% for metal products and 41% for chemical products.

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[12] We defined transport chain alternatives based on their frequency in the CFS. Transport chains that occurred with a frequency of 96 or higher were considered as possible choice options.

[13] The dependent (choice) variable (U_i) in Equation 1 is defined based on the classification on Table 1

[14] The maximum gross weight of the trucks is 60 tonnes in Sweden and Finland compared to 40 tonnes in most other European countries

Descriptive statistics are presented in Table 2. On average, 2 % of all shippers had access to rail at origin and 0.4 % had access to quay at origin. The equivalent figures for metal products and chemical products are 57 and 0.03 % for rail access, and 0.5 and 0.03 % for quay access, respectively. Much to the benefit of the econometric analysis, the CFS has an extensive variation in terms of average shipment values, shipment weights, and transport cost and time.

2.2. Econometric results

Table 3 presents estimation results from the MNL model presented in Equation 1 for 16 commodity groups. The choice alternatives in each model are a discrete combination of a transport chain and shipment size. By and large, the results are plausible and are in line with expectations. Transport cost has a negative effect on the utility of a choice alternative. This is in line with theory which predicts that higher delivery costs make a choice alternative less attractive.

We used a single cost coefficient for all alternatives, building on the idea that 1 SEK is 1 SEK, whatever the alternative it is spent on. Other forms than linear could be tried for the cost specification (such as logarithmic, spline or a combination of linear and logarithmic), but to compare the deterministic model version of the SAMGODS with the stochastic model presented in this paper, it is best to use a linear cost specification, since the former uses linear costs.

The variable for inventory costs during road transport (transport time multiplied by value of the shipment) has the expected (negative) sign and is highly significant for most commodity groups. This variable captures time costs related to the capital cost of the inventory in transit and maybe also those related to deterioration and safety stock considerations. The time-dependent link-based transport costs (labour and vehicle costs) have already been taken into account in the transport costs. Estimation of the inventory cost variable for chains involving rail and sea did not lead to significant coefficients. This is probably due to the possibility that capital costs of an inventory in transit are most relevant for truck transport. Also, the shipment size structure may be providing such a self-selection that for these goods, choice happens on other grounds, as value densities are low.

The access to rail/quay dummy variables was included in the utility functions of choice alternatives where rail/quay was used as the first or second mode in the chosen transport chain. The interpretation of the parameter values is that shippers located in the proximity of or access to rail track or quay yard are more likely to choose chains that start with a rail/quay leg (or use these modes on the second leg of the chain). The two dummies are, however, not significant for most commodity groups.

For most commodity groups, we find significant positive effects for the value density (the value of the shipment divided by its weight) variable. The relevant alternatives for this variable are transport chain alternatives involving the two smallest shipment size categories (0-50 kg and 51-200 kg). The positive sign, therefore, implies that high value products correlate with smaller shipment sizes, which might also imply frequent shipments. We also find that international shipments tend to be shipped more using chains that use rail, ferry or vessel. The transport chain-specific constants (which are estimated system-wide, not zone-specifically) mostly have negative signs and are significant. This is expected given that trucking, the reference chain type, is preferred to the other modes for its flexibility and ease of access (which are not included as explanatory factors in the models since they are not measured in the CFS).

3. From Deterministic to Stochastic Logistics model

3.1. SAMGODS review

The Swedish national freight transport model- SAMGODS- is one of the models that applies the aggregate-disaggregate-aggregate (ADA) framework (see: de Jong and Ben-Akiva, 2007; Ben-Akiva and de Jong, 2013).[16] This framework is also used in the national freight transport models of Norway and Denmark and the model for the Flanders Mobility Masterplan (Belgium). Furthermore, its logistics costs function has also been used in US freight models (e.g. in RSG, 2015). The ADA model framework (see Figure 2) starts with an aggregate model for the determination of flows of goods between production (P) zones and consumption (C) zones (being retail for final consumption; and further processing of goods for intermediate consumption). The PC flows are derived from a gravity-type model. After the determination of these PC flows, comes a disaggregate "logistics" model, that on the basis of PC flows produces OD (origin-destination) flows for network assignment. A PC flow that uses the transport chain road-sea-road

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[16] Akin to de Jong and Ben-Akiva (2007) a recent study by Zhao et al (2015) developed a freight temporal assignment model where disaggregate methods are used to assign aggregate annual flows to aggregate daily flows. We note there are other approaches to simulating freight flows at the national or broad regional levels using different cost functions, micro-simulation and agent-based approaches or direct-demand modeling in various countries, which are reviewed by Chow et al. (2010) (especially US studies) and de Jong et al. (2013) and Liedtke (2009) (especially European studies). Wisetjindawat et al. (2007) also developed a micro-based freight model for the Tokyo Metropolitan area.

between the production and consumption locations contributes to three OD flows (one for each of the modes in the chain).

The logistics model in turn consists of three steps (see Figure 2):

A. Disaggregation of zone-to-zone flows to individual firms at the P and C end;
B. Models for the logistics decisions by the firms (shipment size, trans-shipment locations and modes in a transport chain); This gives OD flows at the level of the annual firm-to-firm flows;
C. Aggregation of the information per shipment to zone-to-zone OD flows for network assignment.

This model structure allows for logistics choices to be modelled at the level of the decision-maker. The network assignment is an aggregate model and is represented by the last A in ADA.

When the logistics model within the ADA-framework for Sweden (and Norway) was first conceived, the idea was that the logistics model would be estimated on data at individual shipment level from the Swedish CFS (see de Jong and Ben-Akiva, 2007, section 7). Since the deterministic logistics module as such is complex and the estimation of disaggregate models would take a significant amount of time, a ‘preliminary’ or ‘prototype’ version of the logistics model was developed in both Sweden and Norway (see de Jong and Ben-Akiva, 2007, section 8) in 2005/2006. This version did not require disaggregate estimation. Instead it relied on a cost minimisation per firm-to-firm (f2f) flow, where for each f2f flow only one alternative (namely the one with the lowest total logistics cost) is chosen. Because it uses different transport solutions for different firm sizes and shipment sizes, the all-or-nothing character of the deterministic model is reduced.

After the prototype had been developed, it has been improved in a number of rounds and also calibrated to aggregate data for a base year, but the current official version of the SAMGODS logistics model still uses a deterministic logistics model.

3.2. Stochastic Model procedure

We programmed a prototype stochastic logistics model for Sweden based on the estimated transport chain and shipment size models for two commodities: metal products and chemical products. The stochastic logistics model was estimated on shipments from the CFS 2004-2005. In the implementation, we do not use the CFS records directly, but we apply the estimated transport chain and shipment size models from Section 2 to the annual firm-to-firm (f2f) flows that are also used in the current deterministic logistics model. These f2f flows are taken from the first step of the logistics model (step A: disaggregation; see Section 3.1), which remained the same in this prototype. For every f2f flow within a commodity group, the new prototype stochastic logistics model now predicts the choice of transport chain and shipment size and it does so by producing choice probabilities for every available alternative.

During the application of the stochastic logistics model the following steps are performed:

a) *Determine the longlist of transport chains.* This step fully corresponds to the corresponding step in the deterministic model. Transport chains with optimal transshipment locations are determined for each of the chain types distinguished within the deterministic model. For these chains, transport distance and time are calculated. Unimodal Level of Service matrices are read in for all possible chain leg modes. Then optimal chains are constructed using a one-to-many algorithm that follows a stepwise approach in adding extra legs to chains and determining the optimal transfer locations (Significance, 2015). Since we do not observe the transhipment locations in the CFS, we could not include this choice in estimation. Therefore, in the stochastic prototype, the determination of the optimal transhipment locations for each available chain type from the set of available locations is still done deterministically.

b) *Reduce the number of chain types to the more limited set (shortlist) distinguished in the stochastic model by a deterministic choice amongst similar chain types.* Within the deterministic model several rail modes (container train, feeder train, wagonload train, system train) and sea modes (direct sea, feeder vessel, long-haul vessel) are available. On the other hand, within the stochastic model only one rail and one sea mode are distinguished (due to the classification used in the CFS). To select the rail and sea modes to be used in the stochastic model, as well as to determine the vehicle types to be used on each leg, we still apply the deterministic model. This has to be done for all of the available weight class (as shown in Table 1) choice options separately. After step (b) the best chains and vehicle types are available for the choice set of chain types and weight classes used within in the stochastic model:

Chain types:
Truck
Vessel
Rail
Truck-Vessel
Rail-Vessel
Truck-Truck-Truck
Truck-Rail-Truck
Truck-Ferry-Truck
Truck-Vessel-Truck
Truck-Air-Truck
Truck-Ferry-Rail-Truck
Truck-Rail-Ferry-truck
Truck-Vessel-Rail-Truck
Truck-Rail-Vessel-Truck

However, not all the above choice options will be available for each commodity. As an example, Figure 3 shows the combinations of transport chain type and weight class that are available in the stochastic model for commodity metal products (based on the actual frequencies in the CFS 2004-2005).

c) *Calculate the utilities for each of the choice options in the stochastic model.* In step (b) the number of available chain types has been reduced to at most 14 the maximum number of chain types distinguished within the stochastic model. Within the third step the utility functions are calculated for each of the available choice options (combinations of transport chain and shipment size) given above. The estimated coefficients are multiplied with the relevant chain input values obtained from the chains determined in step (b). In this step there is no information available on the value of goods (expressed in SEK) or the value density (expressed in SEK/kg) on specific firm-to-firm relations. Therefore, the average commodity value is used in application of the model. The dummy coefficient for direct rail access is always applied to PC chains consisting of a single rail leg and never for the other chains. Quay access is not used in the implemented models for metal and chemical products.

d) *Calculation of the choice probabilities.* When the utilities have been calculated for all available transport chain types and weight classes, the probability for each choice option can be calculated in the usual way for multinomial logit models.

e) *Aggregation of flows.* Like the deterministic model, all firm to firm flows are aggregated to obtain OD-flows. However, instead of the single best chain generated by the deterministic model, we now aggregate over all choice options and weight each choice option with the probability calculated in step (d).

3.3. Calibration procedure for the stochastic model

The stochastic logistics model described above includes alternative-specific constants for all transport chain alternatives (minus one). This means that the model will reproduce the market shares (in terms of the number of shipments) for the chains as they are in the estimation data (which is based on the CFS, but also depends on the question whether we have level-of-service data for a particular transport chain and PC relation) in the current deterministic logistics model. This is not necessarily a good reflection of the actual importance of the various modes for the commodity involved. We also have observed aggregate data on the tonne-kilometers by mode from transport statistics). For metal products and chemical products these numbers for the year 2006 are in the columns labelled ‘statistics’ in Table 4.

When we compare the tonne-km by mode (by OD-leg, so also access/egress tonne-km are counted) from the uncalibrated stochastic model at the overall system level to these observations, we see that it overestimates the road and the sea tonne-km for both products. For metal products there is some underestimation of rail, and for chemical products the stochastic model predicts a very limited (less than one million tonne-km) use of rail transport. This is in line with the CFS, but not with the calibration data (where rail has a market share of more than 10% for chemical products). The deterministic logistics model (without the rail capacity module) on the other hand overestimates the observed rail tonne-km.

To calibrate the stochastic logistics model, we use the observed tonne-km shares as targets and add to each transport chain alternative constant in the utility functions of the stochastic model:

$$\mathrm{Ln}\ (O_j/M_j) \qquad (2)$$

In which:

O_j: observed share of mode j

M_j: Modelled share of mode j

This makes under-predicted modes more attractive and over-predicted ones less attractive. To reach the observed targets, this procedure needs to be repeated several times; it is an iterative calibration procedure (see Figure 4 for details). For the comparison of elasticities in this report we performed a limited number of iterations with the stochastic model for both metal products and chemical products, which brought us much closer to the observed targets, but still not very near.

4. Deterministic vs. Stochastic, a comparison using two commodity groups

4.1 Method

The stochastic approach applied in this paper is intended to be a substitute or complement to the deterministic model, which currently constitutes the very heart of the logistics model in the SAMGODS model system. For metal products and chemical products, both the deterministic and the stochastic model have been implemented into an executable. By switching these executables when running the SAMGODS model system, we may conveniently switch between the deterministic and the stochastic models. Both models operate on the same set of input data when it comes to demand matrices and costs for 2006.

All results in this section have been obtained using the base scenario of the SAMGODS version 1.0 (April 2015). This scenario has been run without taking into account railway capacity restrictions. Since the scenario was originally calibrated using the Rail Capacity Management module, model output may significantly deviate from statistics. For example, the total rail tonne-km is much larger in model output than in transport statistics.

The results in terms of tonne-km per mode are derived from the direct output from the deterministic and stochastic logistics model. These are less precise than those from the corresponding assigned quantities, and introduces extra uncertainty in the results, in particular when it comes to computed tonne-km within Swedish territory.

In the first step, we check the outcome of the model runs against statistics. Table 4 shows that both the deterministic and the stochastic model substantially overestimate the tonne-km performed in Sweden. Another observation that can be made is that the deterministic model calculates relatively high shares for rail while the stochastic model calculates relatively high shares for road and sea. Both the overestimation of the total tonne-km and the deviation from the modal split in the statistics will have consequences for the calculation of the elasticities.

In the next step, we compare the models' responses to perturbations in input data. We express the sensitivity of the models with help of elasticities, which we define as the ratio of the change in an output variable to the change in an input variable, both measured in percentages. The model comprises large sets of both input and output data. Only a few elasticities are presented here. One should also note that the total demand per commodity is constant. Our choice has been to vary, on the input side, the link costs that includes the distance and time-based costs for all vehicle types within road, rail and sea and on the output side, tonne-km in Sweden.[17] In Table 5 we summarize the investigated scenarios.

4.2 Comparison of elasticities

Results for metal products

In Table 6, results for change in tonne-km in Sweden are shown for the different scenarios, computed with the deterministic and the stochastic model. We make the following observations:

- All own price elasticities have the expected sign.
- The own price elasticities for changes in road and rail cost are in all cases much smaller in the stochastic model than in the deterministic model. This is in line with our expectations: we expected that the inclusion of other factors than costs (i.e. value density and the alternative specific constants) directly in the utility function of the stochastic model and the move away from the all-or-nothing choice in the deterministic model would reduce the modal shifts (that are calculated for the deterministic model). Especially for road cost changes, the own elasticities calculated with the stochastic model are more plausible (e.g. they do not become as strong as -2.87 as in the deterministic model). For changes in the sea transport cost, some own price elasticities are stronger in the deterministic model and some in the stochastic model. The own price elasticities can differ substantially between cost increases and decreases (in a logit model elasticities for increases and decreases do not have to be the same, this depends on where the starting point is located on the S-

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[17] Tonne-km in Sweden is the sum of the domestic transports and the domestic parts of international transports that are carried out in Sweden.

shaped logit curve). The own price elasticities can also differ between small and large cost changes, but for the deterministic model for metal products we do not see clear thresholds below which the effects are small and above large. Overshooting seems to be more of a problem than stickiness, also for the smallest changes that were tested.

- In most cases the cross-price elasticities have the opposite sign of the own price elasticity, which is what one should expect from a model in which the modes would be mutually exclusive ('competing') alternatives. However, there are some exceptions both in the deterministic and the stochastic model. The reason is that transport chains in which several modes are combined (e.g. with rail as main haul mode and road for access and egress). As a result, increasing the cost of rail transport could lead not only to an increased share of the road only chain (competition), but also to a reduced road use in the road-rail-road chain (complementarity)[18]. This usually refers to rather short road access and egress distances, but still it reduces the elasticities (in absolute values) and can even lead to cross-price elasticities with the same sign as the own price-price elasticities.
- The cross-price elasticities differ substantially between the different modes. Transfers to/from rail are very small in the stochastic model or nearly all cost increases and decreases. This could imply that current rail shippers are captive to the mode to some extent (note that metal products are characterized by the dominance of one big shipper). On the other hand, it could also imply that other modes are competitively priced to rail, implying that larger price incentive or availability of infrastructure is needed to attract more shippers to rail.

Results for chemical products

In Table 7, results for change in tonne-km in Sweden are shown for the different scenarios, computed with the deterministic and stochastic model. The following conclusions can be drawn from this:

- In all cases, the own price-price elasticities have the expected sign.
- As expected, all own price elasticities for changes in road, rail and sea transport cost are smaller in the stochastic model than in the deterministic model. For all modes, the own price elasticities of the stochastic model seem more plausible than the own price elasticities of the deterministic model. The deterministic model has own price elasticities

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[18] Furthermore, there can also be changes in shipment size in both models as a result of cost changes.

that go beyond -6. Again, there are substantial differences between cost increases and decreases. Also for chemical products, overshooting seems to be more of a problem for the deterministic model than stickiness.

- The own price elasticity of rail costs is in most cases stronger for chemical products than for metal products. This is all probably due to the lower share of rail transport for chemical products compared to metal products. The low rail share for chemical products implies a high sensitivity.
- In most cases the cross-price elasticities have also the opposite sign as the own price elasticities. For the stochastic model, this is almost always the case. For the deterministic model, there are more exceptions which can be explained by stronger complementarities between modes.

4.3 General results

The own price elasticities for changes in transport cost are in nearly all cases much smaller in the stochastic model than in the deterministic model.

Large differences in modal split in the base (see Table 4) lead to different elasticities.

Elasticities differ according to commodities, regions, distance class, modelling approaches and measures (tonne, tonne-km, vehicle-km), see e.g. de Jong et al. (2010). This source does not contain recommendations per commodity type. For all commodities, the recommended road tonne-km own price elasticity on the number of tonne-km by road through mode choice in de Jong et al. (2010) is -0.4 and the lower bound provided is -1.3. Some of the road costs elasticities of the deterministic model for metal and chemical products are clearly beyond this lower bound. The own elasticities, measured in tonnes, calculated using a weighted logit mode-choice model for the Öresund region (Rich et al., 2009) are in about the same range as the own elasticities measured in tonne-km from the stochastic logistics model calculated in this paper.

Table 8 contains some other elasticity values from the literature that are more recent than the review of de Jong et al. (2010). The bottom two references come from models that include multimodal or intermodal transport chains where modes not only compete, but can also be complementary. This reduces the elasticities (in absolute size). The model implemented in this paper also works with transport chains. The recent elasticities are often lower than the recommended value of -0.4. Taking this new evidence into account, the recommended value would rather be -0.3. This is in line with the stochastic model but not with the deterministic model for metal and chemical products.

Generally, the elasticities are lower in the stochastic model than in the deterministic model. This is especially true for the rail mode, where the own price and cross price elasticities of increased and decreased rail costs are much lower in the stochastic model. The same, but to a lesser degree, is true for the cross price elasticities for road and sea. This is a major improvement compared to the deterministic model that often overestimates shifts to/from rail. The elasticities indicate that the problem of overshooting - that is prevalent in a deterministic model when testing different policies – can be solved by moving to a disaggregate stochastic model.

The pattern for increases versus decreases and for scale/non-linear effects is not so clear, though we do observe different elasticity values for cost increases and reductions and for different levels of the costs change.

5. Conclusions and ideas for further research

This paper has presented new estimation results for a disaggregate stochastic model of transport chain and shipment size choice for many different commodities and implementation results (elasticities) for two of those commodities in the context of the Swedish national freight transport model. For the estimation of choice models, we used the Swedish Commodity Flow Survey (CFS) from 2004/2005. Parameter estimates from these models were then used for implementing a random utility, i.e. stochastic, logistics model, replacing existing deterministic components in the Swedish model system.

We have setup a stochastic logistic model for two commodity groups, metal products and chemical products. Although the stochastic model is implemented for the two commodities, we have estimated multinomial logit models for 14 commodities for which a stochastic model could be implemented in the future. We compared own price and cross-price elasticities with respect to link costs road, rail and sea for tonne-km between the stochastic and deterministic models for the two commodities, which has not been done before for such models. These elasticities differ between the two models, they are usually smaller (in absolute values) in the stochastic model, confirming that the problem of potentially large demand responses (overshooting) is solved or at least reduced in the stochastic logistics model. The road tonne-km own price elasticities calculated in the stochastic model are in line with recently published elasticities and recommend as these lower values (-0.3) than earlier studies (-0.4)

In future endeavors, the difference between the two models could be further studied by looking at elasticities on other output measures such as vehicle-kilometers, number of vehicles crossing a screenline, etc. Similar models can be estimated on the Swedish CFS 2009, the CFS 2016, the French ECHO data, the US CFS and hopefully also on future surveys of this kind in other countries. In estimating such models, other costs specifications (logarithmic, linear and logarithmic, splines) as well as more flexible substitution patterns between alternatives (e.g. nested logit, mixed logit) could be tested.

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Table 1: Weight categories inside and outside Sweden, as stated in the 2004/2005 CFS

Category	From (kg)	To (kg)	Freq.	%
1	0	50	703,939	24.36
2	51	200	153,222	5.3
3	201	800	160,420	5.55
4	801	3000	157,891	5.46
5	3001	7500	136,884	4.74
6	7501	12500	127,583	4.42
7	12501	20000	161,688	5.6
8	20001	30000	210,919	7.3
9	30001	35000	207,622	7.19
10	35001	40000	344,695	11.93
11	40001	45000	340,498	11.78
12	45001	100000	153,857	5.32
13	100001	200000	10,835	0.37
14	200001	400000	7,238	0.25
15	400001	800000	6,417	0.22
16	800001	-	5,641	0.2
Total			2,889,349	100

Table 2: Descriptive Statistics

Commodity group*	Rail Access (%)	Quay Access (%)	Shipment weight (KG)	Shipment value (SEK)	Value density** (SEK/KG)	Transport costs (SEK)	Transport time (Hours)	Transport distance (KM)	No. of observations /shipments
Wood (6/7)	15	0.05	14,176	53,150	2,599	7,618	7.1	449.3	21,051
Textile (09)	0.4	0.006	77.32	12,040	786	4,200	5.9	448	27,649
Iron ore (15)	46	0	4,158,336	2,328,523	13.2	162,468	10.9	670.8	480
Nonferrous ore and waste (16)	32	0.13	119,762	931,699	1,203.6	1.63e+09	3.4	234.4	724
Metal products (17)	57	0.5	6,556	31,943	24	3,684	3.5	256	34,627
Earth, gravel (19/20)	1	0.12	88,461.6	37,745	17.4	13,302	3.1	183.6	2,950
Coal chemicals (22)	0.1	0.04	1,732.3	1,124,820	14,728	6,423.9	7	519	1,375
Chemical Products (23)	0.03	0.03	4,023	42,907	288	6,783	10.37	616	37,648
Paper pulp (24)	66	0.42	112,297	448,287	8.4	29,636	25	891	931
Transport Equip (25)	2	0.004	827.8	77,913	1,094	8,347	6.3	438	35,122
Metal manufactures (26)	5	0.01	2,291	56,254	431.6	3,803	4.8	356.8	43,634
Glass (27)	1	0.02	1,680	27,209	139.8	4,111.9	5.4	410.5	11,045
Leather textile (29)**	2	0.004	488.8	13,978.5	2,416				176,547
Machinery (32)	4	0.003	265.7	25,725.6	8,030	10,423.8	3.1	223.1	227,164
Paper board (33)	6	0.02	6,170	43,117	424.9	6,228	4.7	345.1	67,551
Wrapping material (34)	50	0.004	28,007	51,538.6	4.4				1192
All CFS Commodities	2	0.4	26,011	37,122	1,231				2,897,175

*SAMGODS commodity classification number in parenthesis. **Note that the mean of the value density variable is not calculated by dividing the mean values of shipment value and weight for the whole sample. It is calculated as the mean of the value density for each shipment in the CFS. The two values could be close to each other if both variables are greater than or equal to one. For some observations, however, the weight and value variables are recorded as having values less than one in the CFS, which explains the difference between the two statistics.

Table 3: Multinomial Logit model results (Estimated coefficients; t-ratios within brackets; ** indicates significance at 95% level)

Variable	Relevant alternative	Parameter Estimates								
		Textile (09)[1]	Iron ore (15)	Nonferrous ore and waste (16)	Coal chemicals (22)	Paper pulp (24)	Transport Equip (25)	Metal manufactures (26)	Glass (27)	Paper board (33)
Cost (SEK per shipment)	All chains	-0.000852 (-7.77)**	0.000599 (0.67)	-4.44e-006 (-3.68)**	-0.00015 (-9.34)**	-1.36e-005 (-5.48)**	-3.03e-006 (-10.14)**	-0.000602 (-17.38)**	-0.0005 (-4.59)**	-1.15e-005 (-11.82)**
Transport time (in hours) times value of goods (in SEK)	Truck	-3.24e-008 (-2.08)**	-8.31e-006 (-0.05)	-1.07e-007 (-2.33)**	-9.09e-009 (-2.89)**	-1.71e-006 (-9.25)**	-6.78e-008 (-7.58)**	-5.80e-008 (-2.48)**	-2.81e-008 (-0.46)	-1.35e-007 (-6.43)**
Dummy variable for access to rail track	Rail	-0.0479 (-0.02)		5.70 (16.96)**		0.640 (2.51)**	-0.0313 (-0.06)	-0.445 (-1.23)	7.89 (6.89)**	1.64 (19.19)**
Dummy variable for access to quay	Ferry/vessel	-0.165 (-0.29)		1.93 (1.97)**	-0.282 (-0.47)		1.36 (3.53)**	-0.00618 (-0.00618)	1.24 (4.06)**	0.170 (0.61)
Value density (SEK/KG)	All modes: smallest 2 shipment sizes	0.0182 (36.33)**	-0.05 (1.08)	0.000456 (0.97)	0.000315 (9.41)**	0.001 (2.96)**	0.0156 (46.73)**	0.0176 (26.35)**	0.0198 (6.11)**	0.0504 (26.45)**
Dummy variable for international shipment	Rail, Ferry, Vessel	0.881 (8.17)**		3.89 (4.56)**	1.21 (4.36)**	1.14 (3.99)**	4.84 (53.39)**	0.188 (1.60)	2.45 (6.21)**	2.60 (51.27)**
Dummy variable for Air	Constant				0.135 (0.00)		-7.78 (-25.64)**	0.00693 (0.00)		
Dummy variable for rail	Constant					-2.27 (-7.08)**				-5.12 (-124.1)**
Dummy variable for Truck-Rail-Truck	Constant	-10.6 (-11.91)**		-8.06 (-26.50)**		-6.16 (-5.99)**	-7.99 (-53.24)**	-8.24 (-29.07)**	-8.11 (-16.41)**	-4.68 (-134.5)**
Dummy variable for ferry	Constant	-2.49 (-18.27)**		-5.56 (-7.20)**	-2.08 (-9.33)**	-2.52 (-8.69)**	-6.25 (-74.17)**	-0.840 (-7.17)**	-4.33 (-12.61)**	-4.96 (-156.44)**
Dummy variable for Rail-Vessel	Constant					-4.17 (-7.34)**				
Dummy variable for Truck-Vessel-Truck	Constant					-7.67 (-14.02)**	-6.10 (-69.80)**	-0.0179 (-0.03)	-8.27 (-9.76)**	-4.91 (-160.6)**
Dummy variable for truck	Constant	Fixed								
Number of observations Final log-likelihood Rho-square		22623 -24350.2 0.637	59 -13.797 0.792	555 -1336.3 0.193	925 -2064.1 0.208	632 -1628.3 0.14	29616 -39717.7 0.641	36965 -67048.2 0.476	10512 -21250.2 0.435	58384 -88959.3 0.633

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[1] SAMGODS commodity classification number in parenthesis.

Table 3 continued…

Variable	Relevant alternative	Parameter Estimates						
		Leather textile (29)[1]	Machinery (32)	Wood (6/7)	Earth, gravel (19/20)	Metal products (17)	Chemical Products (23)	Wrapping material (34)
Cost (SEK per shipment)	All chains	-0.000661 (-13.74)**	-0.000160 (-73.41)**	-3.01e-005 (-10.74)**	-5.75e-006 (-4.48)**	-1.96e-006 (-5.20)**	-1.55e-005 (-40.40)**	-1.34e-005 (-6.99)**
Transport time (in hours) times value of goods (in SEK)	Truck	-8.43e-008 (-2.15)**	5.67e-00 (0.49)	-1.78e-007 (-5.08)**	-5.39e-006 (-8.53)**	-3.78e-007 (-14.57)**	-1.90e-007 (-14.18)**	2.30e-007 (0.78)
Dummy variable for access to rail track	Rail	-0.0165 (-0.05)	-0.148 (-0.43)	5.37 (10.85)**	-0.0496 (-0.06)**	0.703 (4.42)**		2.25 (5.94)**
Dummy variable for access to quay	Ferry/vessel	-0.0165 (-0.02)	-0.0125 (-0.03)	0.653 (3.83)**	3.09 (6.90)**			-0.0502 (-0.09)
Value density (SEK/KG)	All modes: smallest 2 shipment sizes	0.035 (38.75)**	0.0156 (18.99)**	0.0368 (26.05)**	0.0600 (7.10)**	0.132 (149.46)**	0.0269 (109.46)**	0.000600 (0.29)
Dummy variable for international shipment	Rail, Ferry, Vessel			5.69 (22.17)**	5.50 (14.85)**	3.09 (33.37)**	4.75 (65.12)**	3.47 (7.65)**
Dummy variable for Truck-Air-Truck			0.0071 (0.20)					
Dummy variable for rail	Constant	-0.520 (-3.38)**		-10.7 (-18.33)**	-6.33 (-7.95)**			-3.58 (-9.88)**
Dummy variable for Truck-Rail-Truck	Constant	-1.61 (-16.48)**	-4.45 (-12.42)**			-3.97 (-122.2)**	-5.43 (-28.36)**	0.686 (2.07)**
Dummy variable for Truck-Ferry-Truck	Constant	-0.0751 (-0.53)	-2.68 (-7.72)**		-6-71 (-21.48)**	-4.28 (-95.24)**	-4.81 (-68.58)**	-3.12 (-9.95)**
Dummy variable for Vessel	Constant	-4.53 (-31.30)**		-4.34 (-43.83)**				
Dummy variable for Truck –vessel-Truck	Constant		-3.04 (-116.5)**	-3.73 (-23.33)**	-4.86 (-16.91)**	-5.74 (-63.12)**	-2.39 (-27.43)**	
Dummy variable for Truck-Rail-Vessel-Truck			-3.83 (-131.53)**					
Dummy variable for truck	Constant	Fixed						
Number of observations Final log-likelihood Rho-square		55357 -71392.4 0.625	91329 -121097.6 0.642	16765 -39952.108 0.324	2597 -7058.9 0.158	33908 -81898 0.383	36617 -72769 0.382	1100 -3177.61 0.111

Table 4: Million tonne-km for metal products and chemical products within the borders of Sweden according to Trafikanalys transport statistics 2006, * deterministic model and stochastic model

Million tonne-km	Metal products			Chemical products		
	Statistics	Deterministic model	Stochastic Model	Statistics	Deterministic model	Stochastic model
Road	1,217	2,195	3,911	1,608	1,883	2,794
Rail	4,972	6,908	6,406	482	2,013	558
Sea	801	2,509	1,845	1,803	1,843	2,150
Total	6, 990	11,612	12,162	3, 893	5,738	5,501

*See Table 5 in (Vierth, Jonsson, Karlsson, & Abate, 2014) , 1/3 of the international road transports performed inside and outside Sweden are included.

Table 5: Scenarios for comparisons between deterministic and stochastic model

	Decrease in distance- and time based link costs				Constant link costs	Increase in distance- and time based link costs			
Road	-45%	-15%	-5%	-3%	0% (base)	+3%	+5%	+15%	+45%
Rail	-45%	-15%	-5%	-3%	0% (base)	+3%	+5%	+15%	+45%
Sea	-45%	-15%	-5%	-3%	0% (base)	+3%	+5%	+15%	+45%

Table 6: Elasticities calculated in deterministic and stochastic model for all transports of metal products on Swedish territory

Deterministic model	**Road**								**Rail**								**Sea**							
	-45%	*-15%*	*-5%*	*-3%*	*3%*	*5%*	*15%*	*45%*	*-45%*	*-15%*	*-5%*	*-3%*	*3%*	*5%*	*15%*	*45%*	*-45%*	*-15%*	*-5%*	*-3%*	*3%*	*5%*	*15%*	*45%*
Road tonne-km	-2,87	-2,82	-2,06	-2,41	-1,04	-1,06	-1,10	-0,94	0,81	0,79	0,67	0,33	1,18	1,41	0,84	0,53	0,33	0,73	0,07	-0,05	-0,07	0,33	0,15	0,13
Rail tonne-km	0,78	0,63	0,71	0,76	0,38	0,47	0,49	0,41	-0,80	-1,03	-0,81	-0,56	-0,70	-0,81	-0,78	-0,69	0,38	0,21	0,20	0,24	0,33	0,27	0,25	0,28
Sea tonne-km	0,21	0,83	0,20	0,23	0,35	0,28	-0,13	-0,18	1,04	1,58	1,24	0,74	0,52	0,45	0,97	1,31	-1,84	-2,06	-0,71	-0,84	-0,62	-0,70	-0,91	-0,80
Stochastic model	**Road**								**Rail**								**Sea**							
	-45%	*-15%*	*-5%*	*-3%*	*3%*	*5%*	*15%*	*45%*	*-45%*	*-15%*	*-5%*	*-3%*	*3%*	*5%*	*15%*	*45%*	*-45%*	*-15%*	*-5%*	*-3%*	*3%*	*5%*	*15%*	*45%*
Road tonne-km	-0,80	-0,45	-0,22	-0,16	-0,27	-0,22	-0,15	-0,09	0,04	0,03	0,03	0,03	0,03	-0,04	0,07	0,23	0,08	0,11	0,16	0,20	0,11	0,51	0,32	0,21
Rail tonne-km	0,31	0,09	0,17	0,06	-0,06	-0,03	0,00	0,01	-0,04	-0,03	-0,03	-0,04	-0,03	-0,05	-0,05	-0,18	0,01	0,00	-0,02	-0,04	-0,17	-0,10	-0,03	-0,01
Sea tonne-km	1,16	1,98	2,01	3,67	1,55	1,21	0,63	0,38	0,01	0,00	0,00	0,01	0,01	0,00	0,00	0,03	-0,48	-0,61	-0,77	-0,99	-3,05	-4,14	-1,82	-1,12

Table 7: Elasticities calculated in deterministic and stochastic model for all transports of chemical products on Swedish territory

Deterministic model	**Road**								**Rail**								**Sea**							
	-45%	*-15%*	*-5%*	*-3%*	*3%*	*5%*	*15%*	*45%*	*-45%*	*-15%*	*-5%*	*-3%*	*3%*	*5%*	*15%*	*45%*	*-45%*	*-15%*	*-5%*	*-3%*	*3%*	*5%*	*15%*	*45%*
Road tonne-km	-2,14	-1,58	-1,52	-1,19	-6,10	-3,79	-2,22	-1,01	0,68	0,61	0,59	0,78	-1,43	-0,48	0,10	0,25	0,57	1,40	1,80	2,90	-1,19	-1,77	-0,35	0,24
Rail tonne-km	1,37	1,39	1,01	1,07	3,24	2,03	0,73	0,66	-1,83	-2,18	-1,76	-2,07	-0,22	-1,54	-1,25	-1,41	1,18	0,73	-0,56	-1,46	1,67	1,04	1,31	0,48
Sea tonne-km	0,14	0,00	0,21	-0,11	0,04	0,16	0,55	0,02	1,20	1,69	1,40	1,19	1,82	2,32	1,29	1,39	-2,04	-2,00	-1,35	-1,53	-0,36	-0,75	-1,56	-0,70
Stochastic model	**Road**								**Rail**								**Sea**							
	-45%	*-15%*	*-5%*	*-3%*	*3%*	*5%*	*15%*	*45%*	*-45%*	*-15%*	*-5%*	*-3%*	*3%*	*5%*	*15%*	*45%*	*-45%*	*-15%*	*-5%*	*-3%*	*3%*	*5%*	*15%*	*45%*
Road tonne-km	-0,52	-0,32	-0,23	-0,20	-0,33	-0,25	-0,19	-0,12	0,02	0,04	0,03	0,03	0,01	0,03	0,10	0,08	0,07	0,07	0,08	0,00	0,07	0,07	0,04	0,06
Rail tonne-km	0,97	0,69	0,25	0,25	0,30	0,28	0,54	0,24	-0,29	-0,56	-0,28	-0,29	-0,18	-0,25	-0,51	-0,50	0,01	0,01	0,00	0,01	0,00	0,01	0,01	0,00
Sea tonne-km	0,19	0,03	0,08	-0,04	0,29	0,25	0,09	0,06	0,02	0,04	0,00	-0,01	0,00	0,00	0,00	0,00	-0,14	-0,28	-0,20	-0,23	-0,16	-0,12	-0,07	-0,30

Table 8: More recent evidence on mode choice elasticities.

Model	**Road tonne-km own-price elasticity**
BasGoed (national Dutch freight model; de Jong et al., 2011)	-0.274
Strategic Flemish freight model (Grebe et al., 2016)	-0.14
Danish/Swedish regional freight model (Rich et al., 2009)	-0.29 - -0.09
EU Intermodal container model (Jourquin et al., 2014)	-0.14
EU Transtools3 model (Jensen et al., 2016)	-0.49 - -0.21

Figure 1: Cumulative distribution of shipment weight

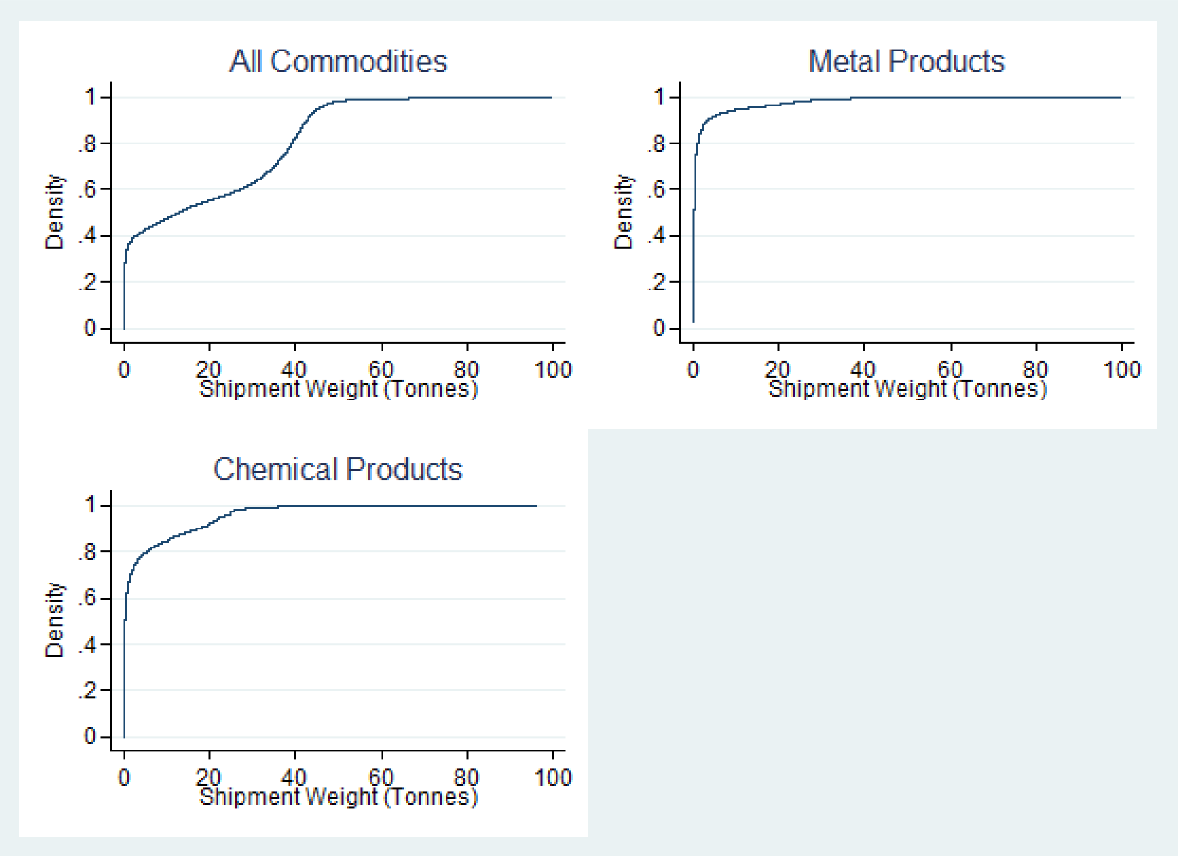
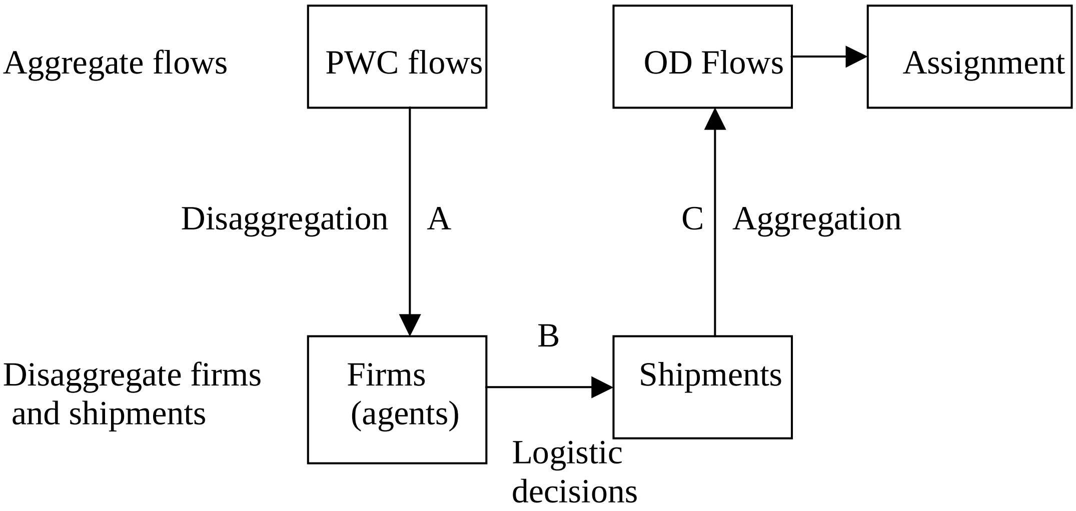
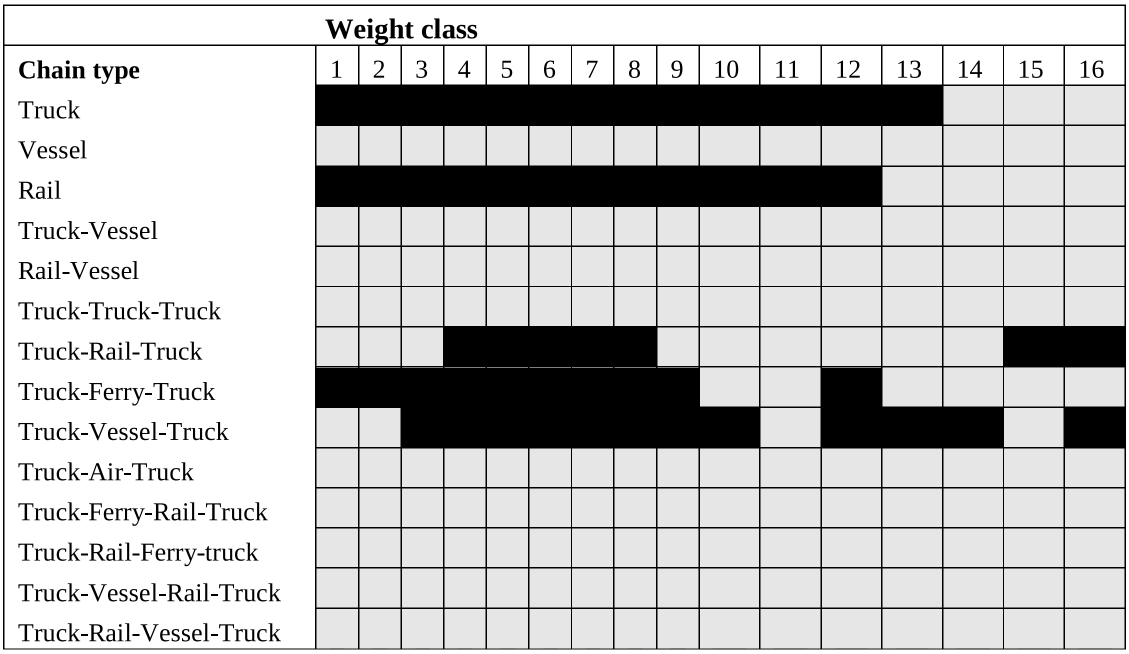


Figure 2: *Structure of the aggregate-disaggregate-aggregate (ADA) model*



Source: Ben-Akiva and de Jong (2013)

Figure 3: Available combinations of chain type and weight class (gray=unavailable, black=available) for commodity Metal products, based on the frequencies observed in the CFS 2004-2005



	Weight class															
Chain type	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Truck	■	■	■	■	■	■	■	■	■	■	■	■	■	□	□	□
Vessel	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□
Rail	■	■	■	■	■	■	■	■	■	■	■	■	□	□	□	□
Truck-Vessel	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□
Rail-Vessel	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□
Truck-Truck-Truck	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□
Truck-Rail-Truck	□	□	□	■	■	■	■	■	□	□	□	□	□	□	■	■
Truck-Ferry-Truck	■	■	■	■	■	■	■	■	■	□	□	■	□	□	□	□
Truck-Vessel-Truck	□	□	■	■	■	■	■	■	■	■	□	■	■	■	□	■
Truck-Air-Truck	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□
Truck-Ferry-Rail-Truck	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□
Truck-Rail-Ferry-truck	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□
Truck-Vessel-Rail-Truck	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□
Truck-Rail-Vessel-Truck	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□

Figure 4: Samgods Calibration Procedure

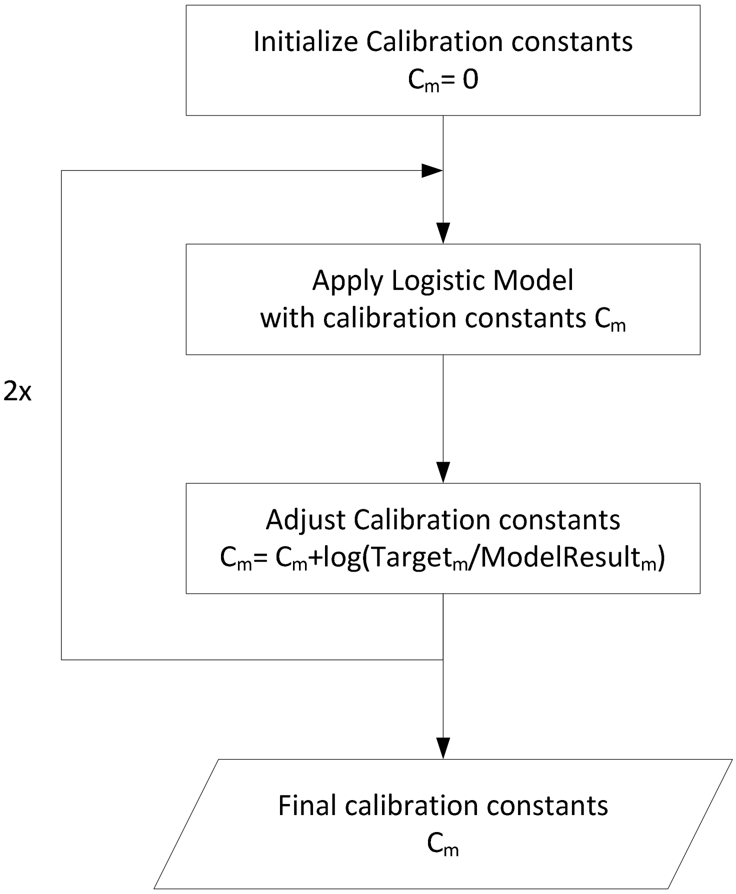


Figure 5: Tonne flows in the SAMGODS model by mode