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CONSTRUCTION OF MULTI-REGIONAL INPUT–OUTPUT TABLES USING THE CHARM METHOD

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Subnational multi-regional input–output tables (IOT) are important tools for studying interregional socio-economic and/or environmental interrelations that help to address a wide range of current societal, ecological and economic challenges. However, the lack of subnational input–output data is a major obstacle which leads to a wide use of non-survey methods. Like other non-survey methods, the cross-hauling adjusted regionalization method (CHARM) was originally developed for the construction of single-regional IOT. In this paper, we extend CHARM to the case of bi- and multi-regional IOT. We find that the original CHARM formula has two limitations that are also of great importance for the single-regional case: First, cross-hauling in interregional trade is implicitly set to zero and, second, accounting balances may be violated owing to structural differences between the regional and national economies. We present a modified formula addressing these issues and examine its performance in terms of a case study.

Keywords: Multi-regional input–output; Non-survey methods; Cross-hauling; Interregional trade; Baden-Württemberg

1. INTRODUCTION

Multi-regional input–output (MRIO) analysis has a long tradition as an important tool for studying the interrelations of different economic structures and trade, as well as their implications for a broad range of societal, economic and ecological issues. The major drawback is that the required data are not readily available from national or supranational statistical agencies. In recent years, the development of global input–output (I–O) databases such as Exiopol (Tukker et al., 2013), EORA (Lenzen et al., 2012a, 2012b, 2013) or the World I–O Database (Dietzenbacher et al., 2013) has led to a tremendous increase in MRIO applications. In global MRIO databases, the term ‘region’ usually refers to a large country (e.g. China, the USA, etc.) or to a group of smaller countries (e.g. the European Union).

Nevertheless, MRIO analysis can also be used to study the interrelationships between sub-national regions within a country and, originally, the theoretical basis of the interregional I–O model was developed by Isard (1951) for the subnational level. Compared with recent developments of MRIOs at the international level, however, the number of up-to-date subnational MRIO tables and applications is much smaller. Examples of subnational MRIO tables and applications in various fields such as (transport) infrastructure planning,

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environmental accounting or energy use include the Netherlands (Eding et al., 1999; Oosterhaven, 2005), China (Liang et al., 2007), Japan (Yi et al., 2007), Spain (Cazcarro et al., 2013) and Australia (Malik et al., 2014).

The main reason for this discrepancy is that the availability of the required data is much more restricted at the subnational level. In the case of international MRIOs, the main task consists of connecting and harmonizing national IOT with international trade data, which are both regularly published for a large number of countries. By contrast, in the case of subnational MRIOs, neither regional IOT nor interregional trade data are available for most countries. Since full-scale surveys tend to be prohibitively expensive, researchers often use a non-survey method to regionalize an existing national IOT. These methods have primarily been designed for the task of deriving a holistically accurate (Jensen, 1980) IOT for a single region from a national table at reasonable costs. A growing body of literature has discussed the various non-survey methods and assessed their strengths and weaknesses (Bonfiglio, 2009; Bonfiglio and Chelli, 2008; Flegg and Tohmo, 2014; Lehtonen and Tykkyläinen, 2014; Round, 1978; 1983; Tohmo, 2004). This literature shows that cross-hauling plays an important role, and non-survey methods that ignore this problem yield unsatisfactory results.[1] The most recent methods are the Flegg et al. Location Quotient (FLQ) (Flegg and Tohmo, 2013b; Flegg and Webber, 1997, 2000; Flegg et al., 1995; Kowalewski, 2015) and the cross-hauling adjusted regionalization method (CHARM) (Flegg et al., 2015; Flegg and Tohmo, 2013a; Kronenberg, 2009, 2012; Kronenberg and Többen, 2013). Both should be used in the context of different IOT layouts regarding the treatment of imports (Flegg and Tohmo, 2013a; Kronenberg, 2012). The FLQ was developed in the context of regional 'type B' tables, whereas CHARM was explicitly designed for regional 'type E' tables.[2]

If MRIO tables are to be constructed at the subnational level, non-survey methods are used to construct a set of single-regional tables, which are afterwards linked to each other via interregional trade estimates (Gallego and Lenzen, 2009; Jackson et al., 2006; Madsen and Jensen-Butler, 1999). This includes the MRIO tables of the 16 German *Länder* (federal states) that are currently being developed by the first author of this paper. In the Industrial Ecology Virtual Laboratory, a recently developed infrastructure for the construction of Australian subnational MRIOs (Lenzen et al., 2014) based on a high degree of automation and high-performance computing, non-survey methods are used to generate priors, which are subsequently aligned with additional raw data. CHARM, as well as its modified version, is implemented in this Lab.

Hence, on the one hand, we have existing literature dealing with the construction of single-region IOT and, on the other, the increasing interest in MRIO tables. The aim of the present paper is to relate these two issues and to discuss how CHARM, which was developed for the single-region case, can be applied in the multi-regional case. In so doing, we also discuss experiences with CHARM over the past few years. Based on our findings, we argue that, with some minor adjustments, CHARM can be a useful tool for

[1] The consequences of ignoring cross-hauling are identified by Jackson (1998, p. 235) as follows: "neglecting cross-hauling [...] will result in overestimates of regional supply and correspondingly inflated output multipliers".

[2] The difference between 'type B' and 'type E' tables lies in their treatment of imports. 'Type B' tables depict the intermediate and final demand for products from domestic production, whereas 'type E' tables depict total intermediate and final demand (domestic production and imports). For more details, see Kronenberg (2012).

the development of MRIO tables. Nevertheless, we would not suggest that a non-survey method like CHARM can dispense with the need for survey data; we would rather treat the use of a non-survey method as the first step in a 'hybrid' approach in the sense of Lahr (1993).

The paper proceeds as follows. In the next section, we discuss the original CHARM approach for the single-region case. We then consider the limitations of the original approach. After that, we move from the single-region case to a multi-regional setting, develop a slightly modified CHARM formula, and explain how this modified formula can be used in a multi-regional setting. Furthermore, we provide an empirical test for the modified CHARM formula, using an official IOT for Baden-Württemberg as a benchmark. The final section presents our conclusions.

2. THE ORIGINAL CHARM FORMULA

The original CHARM formula, as presented by Kronenberg (2009), is used to estimate regional gross imports and exports, given a national type A or E IOT, along with information (estimates or survey based) on regional intermediate consumption, gross output and domestic final demand. This initial situation is shown in Table 1. We assume that good estimates for the regional **Z** matrix (regional intermediate demand, influenced by regional technology) and the regional **d** vector (regional final demand, influenced by regional preferences) are available or can be constructed on the basis of superior data. Note that, in type A or E tables, the matrix **Z** includes intermediate demand from regional sources as well as imports. In type B tables, by contrast, all imported products are recorded as a row vector near the bottom of the table. Depending on the research question, some analysts prefer type B tables, while others prefer type A or E tables.[3] Theoretical considerations (Kronenberg, 2012) and empirical analyses (Flegg and Tohmo, 2013a; Kronenberg and Többen, 2013) suggest that FLQ methods should be used for the regionalization of type B tables, whereas CHARM should be used for type A or E tables.[4]

The crucial task is to come up with plausible estimates of regional trade (the vectors **e** and **m**). As in the classical commodity-balance (CB) approach, these items are needed to calculate the regional trade balance for each commodity, which is identical to net exports:

$$b_i^r \equiv e_i^r - m_i^r = x_i^r - z_{i\cdot}^r - d_i^r, \tag{1}$$

where b_i^r denotes the trade balance (CB) or net exports of product i by region r, e_i^r and m_i^r denote r's exports and imports, x_i^r, $z_{i\cdot}^r$ and d_i^r denote regional output, total intermediate and final demand and $\cdot$ indicates summation over indices. In the supply–demand pool or CB approach, it is assumed that a sector is either import- or export-orientated. Where $b_i^r < 0$, regional output is insufficient to satisfy regional demand, so that regional gross imports are set equal to the absolute value of regional net exports, whereas gross exports are set

[3] In our experience, regional scientists often prefer type B tables because they are mainly interested in regional output and employment, while ecological economists often prefer type E tables for studies of environmental impacts.

[4] The application of CHARM to supply–use tables is straightforward. In Table 1, total domestic product output from the supply table would be used instead of x_i^r, while z_i^r and d_i^r would be replaced by total intermediate and final use of products from the use table.

TABLE 1. Regional type E IOT.

		Sector							
		1	...	j	...	n	Final demand	Exports	Total use
Sector	1	z^r_{11}	...	z^r_{1j}	...	z^r_{1n}	d^r_1	e^r_1	u^r_1
	$\vdots$	$\vdots$	$\ddots$	$\vdots$	$\ddots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$
	i	z^r_{i1}	...	z^r_{ij}	...	z^r_{in}	d^r_i	e^r_i	u^r_i
	$\vdots$	$\vdots$	$\ddots$	$\vdots$	$\ddots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$
	m	z^r_{m1}	...	z^r_{mj}	...	z^r_{mn}	d^r_m	e^r_m	u^r_m
Value added		v^r_1	...	v^r_j	...	v^r_n			
Output		x^r_1	...	x^r_j	...	x^r_n			
Imports		m^r_1	...	m^r_j	...	m^r_n			
Total supply		s^r_1	...	s^r_j	...	s^r_n			

Note: Shaded elements are those to be estimated, whereas unshaded elements are assumed to be known.
Source: Reproduced from Kronenberg (2009).

equal to zero. For $b^r_i > 0$, by contrast, regional output exceeds regional intermediate and final demand, so that imports are unnecessary ($m^r_i = 0$) and the remaining products are exported.

For the estimation of regional gross imports and exports, however, information about the CB alone is insufficient. It is also necessary to have information about the amount of commodities that are simultaneously imported and exported, that is, the amount of cross-hauling, q_i. Generally, q_i can be calculated as

$$q_i \equiv (e_i + m_i) - |e_i - m_i| = v_i - |b_i|, \tag{2}$$

where $v_i \equiv e_i + m_i$ denotes the trade volume.

The basic idea behind the CHARM approach is to calculate the shares of cross-hauling observed in national trade with the rest of the world and then apply these shares to regional data. The calculation of national cross-hauling shares, h^n_i, is carried out according to

$$h^n_i = \frac{v^n_i - |b^n_i|}{(x^n_i + z^n_{i\cdot} + d^n_i)} = \frac{q^n_i}{(x^n_i + z^n_{i\cdot} + d^n_i)}. \tag{3}$$

It is then assumed that regional and national cross-hauling shares are equal for each commodity, such that setting $h^n_i = h^r_i$ allows the estimation of regional cross-hauling from regional data:

$$q^r_i = h^r_i(x^r_i + z^r_{i\cdot} + d^r_i). \tag{4}$$

From regional cross-hauling and CBs, gross exports and imports can, finally, be calculated as

$$e^r_i = \frac{v^r_i + b^r_i}{2} = \frac{q^r_i + |b^r_i| + b^r_i}{2}, \tag{5a}$$

$$m^r_i = \frac{v^r_i - b^r_i}{2} = \frac{q^r_i + |b^r_i| - b^r_i}{2}. \tag{5b}$$

Inserting these values into Table 1 completes the regional IOT. The key assumption of CHARM is that $h_i^n = h_i^r$. Kronenberg (2009) justifies this assumption on the basis that product heterogeneity is the main cause of cross-hauling.[5] This argument suggests that a large share of cross-hauled commodities in output and consumption observed in national data indicates that the respective commodities are characterized by a high degree of heterogeneity, so that the parameter h_i^n may be interpreted as a measure of this heterogeneity. Where $h_i^n = 0$, products are held to be perfectly homogeneous, whereas $h_i^n \to \infty$ for perfectly heterogeneous products. Kronenberg argues that $h_i^n = h_i^r$ is a reasonable assumption, as heterogeneity should be seen as a characteristic of commodities rather than of a specific region.

The assumption that $h_i^r = h_i^n$ is not immune to criticism. Jackson (2014, p. 3) argues that the heterogeneity of a commodity group will depend on the regional product mix, which in turn "will vary geographically for many reasons, including the simple fact that not all commodities within an aggregate commodity group will be produced everywhere". This problem arises whenever a non-survey method is employed to estimate regional structures by using national averages, because all non-survey methods rely to some extent on the assumption of equal technology. This assumption is required to justify the use of national I–O coefficients for the estimation of regional interindustry transactions. In other words, if the product mix significantly differs, the equal technology assumption is violated, and non-survey methods (including CHARM and all others) will deliver unsatisfactory results. Therefore, the argument by Jackson (2014) should be seen as a challenge for the non-survey approach in general and not for CHARM in particular. This lends further support to a generally accepted recommendation: in order to achieve satisfactory results, researchers should never rely completely on non-survey methods and should always try to improve their estimates with 'superior' data whenever possible.

Another important limitation of the original CHARM formulation is that it does not make a distinction between trade flows with other countries and trade flows with other regions in the same country. This may lead to an underestimation of total imports, as will be shown below. Furthermore, if the goal is to construct a bi-regional or multi-regional IOT, it is necessary to estimate the trade flows between all the individual regions. The original CHARM cannot do this. Therefore, we present an extended version of CHARM in the following section.

3. LIMITATIONS OF THE ORIGINAL CHARM

3.1. CHARM in a Bi-Regional Context: Interregional and International Trade

Let us consider the case of two regions r and s, which form a nation n, with $r + s = n$. In the original CHARM approach, it is assumed that heterogeneity observed in national foreign trade is equal to heterogeneity in both regions ($h_i^r = h_i^s = h_i^n$). Regional cross-hauling

[5] See Leigh (1970), Isserman (1980), Norcliffe (1983) and Harris and Liu (1998) for studies of cross-hauling at the subnational level.

of both regions is then estimated via

$$q_i^r = h_i^r(x_i^r + z_{i.}^r + d_i^r), \tag{6a}$$

$$q_i^s = h_i^s(x_i^s + z_{i.}^s + d_i^s). \tag{6b}$$

Since the sum of both regions makes up the nation as a whole, it follows that $(x_i^r + z_{i.}^r + d_i^r) + (x_i^s + z_{i.}^s + d_i^s) = (x_i^n + z_{i.}^n + d_i^n)$. In conjunction with the assumption on heterogeneity ($h_i^r = h_i^s = h_i^n$), it becomes obvious what CHARM is actually estimating, when the cross-hauling of both regions is added up:

$$\begin{aligned} q_i^r + q_i^s &= h_i^r(x_i^r + z_{i.}^r + d_i^r) + h_i^s(x_i^s + z_{i.}^s + d_i^s) \\ &= h_i^n[(x_j^r + z_{i.}^r + d_i^r) + (x_i^s + z_{i.}^s + d_i^s)] = h_i^n(x_i^n + z_{i.}^n + d_i^n) = q_i^n. \end{aligned} \tag{7}$$

In effect, CHARM allocates the cross-hauling observed in national foreign trade to the two subnational regions. This allocation is made by means of a region's share of national output, and its share of intermediate and final consumption. Implicitly, CHARM assumes that no cross-hauling takes place between the two subnational regions. Thus, if there is substantial cross-hauling between the two regions, CHARM will tend to underestimate total trade flows. In order to produce more realistic estimates, CHARM should be further adjusted to reflect the fact that cross-hauling occurs not only between countries but also within countries.

3.2. Valuation of Exports and Imports

Since the core of CHARM consists of the estimation of product heterogeneity in national trade data, it is obvious that accounting practices used by statistical agencies for the generation of such data are transferred to regional trade estimates. Two cases appear to be especially important for the application of CHARM, namely the problems of import/export price differentials and re-exports. Both problems play a prominent role in the consolidation of multi-national IOT (Bouwmeester et al., 2014), yet their consequences for the application of CHARM have not been discussed so far.

First, for the estimation of regional trade, especially in trade and transport services, it is important to be aware of the difference between import and export prices. Exports are valued at 'free-on-board' prices at the border of the exporting country. Imports, by contrast, are valued at 'cost, insurance, freight' (cif) prices at the border of the importing country and include international transport and insurance services (Eurostat, 2008). The effect of these different price concepts on estimates of product heterogeneity can be illustrated for the case of trade services with motor vehicles: the German IOT only report exports of such services but zero imports, which results in $h_i^n = 0$ and, thus, zero cross-hauling in regional trade. Personal communication with the staff of the federal statistical office revealed, however, that Germany does not import trade services with motor vehicles separately; instead, the trade margin is included in the cif-price of imported cars.

CHARM is based on the idea that the CB for each product can be computed from the national IOT. As accounting practices may well differ from country to country, the compiler of a regional IOT should be aware of this problem. The best way to deal with it when using CHARM would be to use national imports and exports that have been valued by the same price concept.

3.3. Treatment of Re-Exports

The second and more important case is the accounting practice for re-exports and its consequence for the interpretation of h_i^n as a measure of product heterogeneity. Because the amounts of exports and imports match exactly in the case of re-exports, they are regarded as cross-hauling in the sense of the CHARM procedure. Here it is important to highlight the conceptual difference between re-exports and exports of domestically produced products. According to the Statistics Division of the UN (2008), re-exports are imported products that are exported with a change in ownership (from resident to non-resident and vice versa), but without any substantial transformation. It is recommended that these products be included in national foreign trade statistics, but the interpretation of h_i^n fails as a measure of heterogeneity for the re-export part in national cross-hauling. As re-exports are ultimately not consumed in the region under study, they cannot be subject to regional brand preferences or different consumer tastes. Re-exported commodities are, furthermore, not produced in the region.

The consequences of re-exports for CHARM become obvious in the domain of definition for h_i^n. Kronenberg (2009) defines $h_i^n \in [0, \infty)$, whereby h_i^n approaches infinity for perfectly heterogeneous commodities. However, according to Equation 3, $h_i^n > 1$ is only possible if $q_i^n > x_i^n + z_{i\cdot}^n + d_i^n$, which means that a certain share of cross-hauled commodities is neither produced nor consumed in the country. In the German IOT, for example, $q_i^n > x_i^n + z_{i\cdot}^n + d_i^n$ arises quite frequently. For regional IOT, the application of CHARM would result in regional imports that exceeded regional consumption, that is, $m_i^r > z_{i\cdot}^r + d_i^r$, and exports that exceeded regional output, that is, $e_i^r > x_i^r$.[6] This means that the cross-hauling estimates produced by the original CHARM include re-exports.

For applications of regional IOT, for example, impact analysis or environmental analysis, such outcomes cannot simply be ignored. When it comes to the estimation of intraregional purchases on the basis of such regional trade estimates, the resulting intermediate and final consumption of domestically produced products will be negative if re-exports are ignored. Alternatively, regional purchase coefficients, which account for re-exports in regional trade explicitly (Lahr, 2001), can be used to derive intraregional purchases, assuming that national re-export shares apply to the region as well. However, if we are interested in trade in commodities that are produced or consumed in the respective region, re-exports should consequently be subtracted from trade data used to estimate h_i^n. In this case, $h_i^n \in [0, 1]$, where $h_i^n = 1$ would be interpreted as indicating perfectly heterogeneous products.

3.4. Accounting Balances

The existence of re-exports in trade data used to estimate product heterogeneity is not the only source of regional trade estimates that exceed regional consumption and production. Owing to the presence of both output and consumption in the denominator of Equation 3, it is possible that $x_i^r < e_i^r$ and $z_{i\cdot}^r + d_i^r < m_i^r$ could occur. The problem may be illustrated by an example.

[6] Note that as $b_i \equiv e_i - m_i \equiv x_i - z_{i\cdot} - d_i$ implies $x_i - e_i = z_{i\cdot} + d_i - m_i$, both $x_i^r < e_i^r$ and $z_{i\cdot}^r + d_i^r < m_i^r$ must occur simultaneously.

Suppose that a product is either not produced or consumed in a region ($x_i^r = 0$ or $z_{i.}^r + d_i^r = 0$), yet cross-hauling is observed in national foreign trade ($h_i^n > 0$). Here CHARM would yield $e_i^r > 0$ in spite of $x_i^r = 0$ or $m_i^r > 0$ in spite of $z_{i.}^r + d_i^r = 0$. Therefore, it is required that $h_i^r = 0$ for $\min(x_i^r; z_{i.}^r + d_i^r) = 0$. This example is the most obvious case for which the problem arises, but such inconsistencies are still possible even if h_j^r is set to zero for $\min(x_i^r; z_{i.}^r + d_i^r) = 0$. The problem arises from the assumptions on which Equation 4 is based.

Consider the case of a rise in regional production of good i while regional consumption remains constant. The additional production will be used for exports. Since most sectors use intrasectoral deliveries as inputs, some of those inputs will be imported. Therefore, one should expect the imports of good i to increase, but to a lesser extent than exports. If both exports and imports increase, this would amount to an increase in q_i. Hence, an increase in production should cause a less than proportional increase in q_i. A similar argument can be made where there is a rise in regional consumption (cf. Kronenberg, 2009, pp. 50–51).

Although these arguments appear plausible, it is the indirect linkage of domestic consumption to exports and output to imports in the current formula that results in inconsistencies. In order to verify this argument formally, it is necessary to distinguish the cases of positive and negative trade balances at the regional and national levels, as follows.

If $b_i^r < 0$, Equation 5a becomes $e_i^r = q_i^r/2$. In order to show in which cases exports exceed output, Equation 4 is substituted into the relation $e_i^r = q_i^r/2 > x_i^r$ and further solved for h_i^r:

$$h_i^r > \frac{2x_i^r}{(x_i^r + z_{i.}^r + d_i^r)}. \tag{8a}$$

Similarly, where $b_i^r > 0$, Equation 4 is substituted into the relation $m_i^r = q_i^r/2 > z_{i.}^r + d_i^r$ and solved for h_i^r, which yields

$$h_i^r > \frac{2(z_{i.}^r + d_i^r)}{(x_i^r + z_{i.}^r + d_i^r)}. \tag{8b}$$

Rearranging both inequalities and setting $h_i^r = h_i^n$ yields the conditions for inconsistent estimates for positive and negative regional trade balances:

$$\frac{h_i^n}{(2 - h_i^n)} > \frac{x_i^r}{z_{i.}^r + d_i^r} \quad \text{for} \quad b_i^r < 0, \tag{9a}$$

$$\frac{h_i^n}{(2 - h_i^n)} > \frac{z_{i.}^r + d_i^r}{x_i^r} \quad \text{for} \quad b_i^r > 0. \tag{9b}$$

Thus, whether or not an estimate of regional cross-hauling for a particular commodity is inconsistent with regional accounting balances solely depends on (i) the parameter h_i^n and (ii) the ratio of regional supply to regional demand for that commodity. As cross-hauling q_i^r consists of imports and exports in equal amounts, there must be sufficient regional supply to provide the required exports if the region is a net importer (condition 9a). If it is a net exporter (condition 9b), regional demand must be sufficiently high to absorb the import part of regional cross-hauling. In the extreme case of $h_i^n = 1$, both conditions coincide and imply that $x_i^r = z_{i.}^r + d_i^r$. For $h_i^n = 0$, it is required that regional output equals zero if the region is a net importer or that regional demand equals zero if the region is a net exporter of product i. The latter is the case discussed above. In other words, the use of the national

TABLE 2. Number of inconsistent CHARM estimates for Germany's federal states.

Federal state	Number of inconsistencies	Percentage of population	Percentage of GDP
Nordrhein-Westfalen	1	21.9	21.8
Bayern	2	15.2	17.9
Baden-Württemberg	1	13.1	14.7
Hessen	17	7.4	8.8
Niedersachsen	8	9.7	8.5
Rheinland-Pfalz	20	4.9	4.3
Sachsen	23	5.1	3.9
Berlin	30	4.1	3.5
Hamburg	28	2.1	3.4
Schleswig-Holstein	25	3.4	3.0
Brandenburg	28	3.1	2.2
Thüringen	30	2.8	2.0
Mecklenburg-Vorpommern	34	2.1	1.4
Saarland	37	1.3	1.2
Bremen	39	0.8	1.1

Source: Own calculation.

cross-hauling shares requires the regional ratio of supply and demand to be sufficiently close to that of the national ratio, whereby the required degree of similarity of regional and national supply-to-demand ratios depends on h_i^n.

Table 2 shows the number of inconsistencies per region that occurred in the construction of an MRIO for 16 German states. The states are rank-ordered by their share in national GDP. Re-exports have been excluded from national trade data used for the estimation, so that these inconsistencies can be attributed solely to regional deviations from national supply-to-demand ratios. It can be seen that the number of inconsistencies tends to decrease as regional size increases. The reason is that the economic structure of small regions is likely to substantially differ from the national average. Bremen, for example, is the smallest German state in terms of GDP and population, yet it is a city state with Germany's second largest seaport. Therefore, Bremen's supply of shipping services, trade, gastronomy and cultural activities exceeds its regional demand to a large extent. On the other hand, its supply-to-demand ratio for sectors such as agriculture and mining is much lower than the national average.

4. THE MODIFIED CHARM FORMULA

4.1. Modified CHARM for Bi-Regional Tables

Starting from the aforementioned limitations of the original CHARM, the development of a modified CHARM must address two aspects. First, accounting balances of the region at hand, as well as of the rest of the nation, must be taken into account. Second, regional trade with foreign countries and interregional trade need to be estimated individually, but in a consistent manner.

The point of departure is a bi-regional accounting framework, as shown in Table 3, where the national table is split into two regions: the region of interest r and the rest of the

TABLE 3. Bi-regional type E IOT.

		Region r			Region s				Exports			
		1	...	N	1	...	n	Final demand	***r***	***s***	Row	Total use
Region r	1	z^r_{11}	...	z^r_{1n}				d^r_1	t^{rs}_1	0	e^r_1	u^r_1
	⋮	⋮	⋱	⋮				⋮	⋮	⋮	⋮	⋮
	m	z^r_{m1}	...	z^r_{mn}				d^r_m	t^{rs}_m	0	e^r_m	u^r_m
Region s	1				z^s_{11}	...	z^s_{1n}	d^s_1	0	t^{sr}_1	e^s_1	u^s_1
	⋮				⋮	⋱	⋮	⋮	⋮	⋮	⋮	⋮
	m				z^s_{m1}	...	z^s_{mn}	d^s_m	0	t^{sr}_m	e^s_m	u^s_m
Value added		v^r_1	...	v^r_n	v^s_1	...	v^s_n					
Output		x^r_1	...	x^r_n	x^s_1	...	x^s_n					
Imports	r	0	...	0	t^{rs}_1	...	t^{rs}_n					
	s	t^{sr}_1	...	t^{sr}_n	0	...	0					
	row	m^r_1	...	m^r_n	m^s_1	...	m^s_n					
Total supply		s^r_1	...	s^r_n	s^s_1	...	s^s_n					

Source: Own elaboration.

country s, with $n = r + s$. Gray-shaded elements are those to be estimated with the modified CHARM, whereas non-shaded elements are those assumed to be known or estimated on the basis of superior data. In this framework, t^{rs}_i denotes exports from region r to region s and imports by region s from r, respectively. This is a framework in the spirit of single-regional type E tables because regional intermediate and final consumption incorporates purchases from domestic output, as well as from interregional and foreign sources. Note that, for a researcher who wants to construct an IOT for one region, the extension to such a bi-regional framework requires very little additional effort, since the table for region s can be calculated as the difference between the national table and the table for region r. As in the double-entry method of Boomsma and Oosterhaven (1992), the explicit treatment of the rest of the country can be used for consistency checks and thus facilitates a consistent estimation of interregional trade.

With information as displayed in Table 3, the estimation of regional trade consists of two steps.

In the first step, foreign imports and exports for both regions need to be estimated. As data about imports from and exports to foreign countries are often available at the regional level, such information can and should be used. A simple alternative would be to allocate foreign trade from the national IOT to both regions, for example, by assuming that imports from abroad are proportional to total domestic demand and exports are proportional to domestic output. Regional foreign trade can then be estimated as

$$m^r_i = m^n_i \frac{z^r_{i\cdot} + d^r_i}{z^n_{i\cdot} + d^n_i} \text{ and } e^r_i = e^n_i \frac{x^r_i}{x^n_i}, \tag{10a}$$

$$m^s_i = m^n_i \frac{z^s_{i\cdot} + d^s_i}{z^n_{i\cdot} + d^n_i} \text{ and } e^s_i = e^n_i \frac{x^s_i}{x^n_i}. \tag{10b}$$

The second step consists of estimating cross-hauling in interregional trade in a similar manner as in the original CHARM procedure, but taking accounting balances of both regions explicitly into consideration. When incorporating these accounting balances, it is important to note that cross-hauling q consists, by definition, of equal amounts of imports and exports. If we are only interested in exports and imports that are produced or consumed in the region (i.e. no re-exports), an upper limit for regional exports from or imports to each region involved in regional cross-hauling is given by

$$\min\left(x_i^r - e_i^r; z_{i.}^r + d_i^r - m_i^r\right) = \max\left[\frac{q_i^r}{2}\right], \tag{11a}$$

$$\min\left(x_i^s - e_i^s; z_{i.}^s + d_i^s - m_i^r\right) = \max\left[\frac{q_i^s}{2}\right]. \tag{11b}$$

The left-hand side of each condition defines the remaining potential for cross-hauling in interregional trade for each region, after subtracting foreign imports and exports. These conditions alone do not, however, ensure that $t_i^{rs} = t_i^{sr}$, if trade flows are estimated for both regions individually. It is, therefore, necessary to define the maximum potential for cross-hauling in trade between the two regions as the minimum of cross-hauling potential of the two regions from conditions 11a and 11b:

$$\max\left[\frac{\tilde{q}_i}{2}\right] = \min\left(x_i^r - e_i^r; z_{i.}^r + d_i^r - m_i^r; x_i^s - e_i^s; z_{i.}^s + d_i^s - m_i^s\right), \tag{12}$$

where $\tilde{q}_i$ denotes the cross-hauling in interregional trade between r and s. After having established the condition of consistency for regional cross-hauling estimates, the remaining task is to estimate the extent to which the regional cross-hauling potential is realized.

Consequently, in the spirit of the original CHARM formula, the estimation of regional cross-hauling can be based on the relationship between observed cross-hauling and cross-hauling potential at the national level. Following on from the definition of cross-hauling potential at the national level as $\max\left[q_i^n/2\right] = \min\left(x_i^n; z_{i.}^n + d_i^n\right)$, the share of observed national cross-hauling in national cross-hauling potential, $\tilde{h}_i^n$, is calculated as

$$\tilde{h}_i^n = \frac{q_i^n}{2\min\left(x_i^n; z_{i.}^n + d_i^n\right)}. \tag{13}$$

$\tilde{h}_i^n$ can be interpreted in the same manner as h_i^n in the original CHARM formula. As cross-hauling is caused by brand preferences and different consumer tastes, a large share of cross-hauling observed in national cross-hauling potential is an indication of a high degree of product heterogeneity. Assuming that $\tilde{h}_i^n = \tilde{h}_i^r$, regional cross-hauling can be estimated as

$$\tilde{q}_i = 2\tilde{h}_i \min\left(x_i^r - e_i^r; z_{i.}^r + d_i^r - m_i^r; x_i^s - e_i^s; z_{i.}^s + d_i^s - m_i^r\right). \tag{14}$$

The final calculation of interregional gross trade flows is carried out in conjunction with regional CBs $\tilde{b}_i^r = -\tilde{b}_i^s = (x_i^r - e_i^r) - (z_{i.}^r + d_i^r - m_i^r)$ analogously to Equations 5a and 5b:

$$t_i^{rs} = \frac{\tilde{q}_i + |\tilde{b}_i^r| + \tilde{b}_i^r}{2}, \tag{15a}$$

$$t_i^{sr} = \frac{\tilde{q}_i + |\tilde{b}_i^s| - \tilde{b}_i^s}{2}. \tag{15b}$$

One might argue that heterogeneity is not solely a characteristic of a product, but rather a characteristic of products specific to the output of both trading partners. This argument would suggest that individual heterogeneity parameters should be estimated from the foreign trade of both regions. This, however, does not necessarily yield results different from the application of Equation 13 to the national table. If regional foreign trade were allocated to the regions according to Equations 10a and 10b, this operation would yield exactly the same values, since foreign trade is allocated proportionally to the regions. On the other hand, if data on regional foreign trade were used, this operation will produce different values for $\tilde{h}_i^r$ and $\tilde{h}_i^s$, leaving us with the question as to which one to use. Nevertheless, the weighted average of both is exactly equal to $\tilde{h}_i^n$.

4.2. The Case of More Than Two Regions

We now consider the estimation of interregional trade for an MRIO table, whereby, for simplicity, the application of CHARM in an MRIO context is illustrated for $p = 3$ regions, namely q, r and s. The initial situation is shown in Table 4, where non-shaded areas denote known data items and gray-shaded areas denote the items to be estimated. It is assumed that regional foreign trade is either given or has already been estimated, for example, according to Equations 11a and 11b. As in the bi-regional accounting framework presented in Table 3, intermediate and final consumption incorporates intraregional purchases, as well as imports from the rest of the world and the rest of the country. In order to balance total use with total

TABLE 4. Multi-regional type E accounting framework.

		Region q			Region r			Region s			Final demand	Exports				Total use
		1	…	n	1	…	n	1	…	n		q	r	s	row	
Region q	1	z_{11}^q	…	z_{1n}^q							d_1^q	0	t_1^{qr}	t_1^{qs}	e_1^q	u_1^q
	⋮	⋮	⋱	⋮							⋮	⋮	⋮	⋮	⋮	⋮
	m	z_{m1}^q	…	z_{mn}^q							d_m^q	0	t_m^{qr}	t_m^{qs}	e_m^q	u_m^q
Region r	1				z_{11}^r	…	z_{1n}^r				d_1^s	t_1^{rq}	0	t_1^{sq}	e_1^s	u_1^s
	⋮				⋮	⋱	⋮				⋮	⋮	⋮	⋮	⋮	⋮
	m				z_{m1}^r	…	z_{mn}^r				d_m^s	t_m^{rq}	0	t_m^{sq}	e_m^s	u_m^s
Region s	1							z_{11}^s	…	z_{1n}^s	d_1^s	t_1^{sq}	t_1^{sr}	0	e_1^s	u_1^s
	⋮							⋮	⋱	⋮	⋮	⋮	⋮	⋮	⋮	⋮
	m							z_{m1}^s	…	z_{mn}^s	d_m^s	t_m^{sq}	t_m^{sr}	0	e_m^s	u_m^s
Value added		v_1^q	…	v_n^q	v_1^r	…	v_n^r	v_1^s	…	v_n^s						
Output		x_1^q	…	x_n^q	x_1^r	…	x_n^r	x_1^s	…	x_n^s						
Imports	q	0	…	0	t_1^{qr}	…	t_n^{qr}	t_1^{qs}	…	t_n^{qs}						
	r	t_1^{rq}	…	t_n^{rq}	0	…	0	t_1^{rs}	…	t_n^{rs}						
	s	t_1^{sq}	…	t_n^{sq}	t_1^{sr}	…	t_n^{sr}	0	…	0						
	row	m_1^r	…	m_n^r	m_1^r	…	m_n^r	m_1^s	…	m_n^s						
Total Supply		s_1^r	…	s_n^r	s_1^r	…	s_n^r	s_1^s	…	s_n^s						

Source: Own elaboration.

TABLE 5. O–D matrix with CHARM estimated row and column sums.

	Region q	Region r	Region s	Total
Region q	0	t_i^{qr}	t_i^{qs}	$t_i^{q\ \mathrm{roc}}$
Region r	t_i^{rq}	0	t_i^{rs}	$t_i^{r\ \mathrm{roc}}$
Region s	t_i^{sq}	t_i^{sr}	0	$t_i^{s\ \mathrm{roc}}$
Total	$t_i^{\mathrm{roc}\ q}$	$t_i^{\mathrm{roc}\ r}$	$t_i^{\mathrm{roc}\ s}$	$\sum_p t_i^{p\ \mathrm{roc}} = \sum_p t_i^{\mathrm{roc}\ p}$

Note: Shaded elements are those to be estimated, whereas unshaded elements are assumed to be known.
Source: Reproduced from Sargento et al. (2012).

supply, imports are accounted for twice: indirectly in intermediate and final consumption and directly as row vectors.

In such a situation, it is crucial to understand that CHARM itself cannot deliver ad hoc estimates of interregional trade flows, but it can deliver information for a stepwise approach. That is, for each product, CHARM delivers row (total interregional exports) and column (total regional imports) sums of an origin–destination (O–D) matrix, whose diagonal elements are zero. Such an O–D matrix is presented in Table 5. The first step of such a stepwise approach consists of estimating total interregional imports and exports, as in the bi-regional case. From the perspective of region q, regional cross-hauling is estimated as in Equation 14, whereby the rest of the country now comprises the other two regions ($\mathrm{roc} = r + s$). Total interregional imports and exports of region q can then be estimated analogously to Equations 15a and 15b. The regional gross trade estimates are consistent in the sense that the sum of regional exports to the rest of the country equals the sum of regional imports from the rest of the country for each product i: $\sum_p t_i^{p\ \mathrm{roc}} = \sum_p t_i^{\mathrm{roc}\ p}\ \forall i$.

The further estimation of the explicit interregional trade flows between the regions (the off-diagonal elements) can be carried out with different kinds of spatial interaction models, for example, with the classical gravity model. This problem is discussed by Oosterhaven (2005), who describes how interregional (as opposed to intraregional) employment multipliers can be estimated if bi-regional IOT for all regions (but no multi-regional IOT) are available. His proposed solution includes the estimation of a lack of intraregional multipliers by means of regression analysis and the estimation of interregional spillover effects (owing to interregional trade) by means of "distance decay formulas found in gravity, entropy, and spatial equilibrium model" (Oosterhaven, 2005, p. 70). Isard et al. (1998), Sargento (2009) and Sargento et al. (2012) give an overview of several methods suitable for such a situation, such as shown in Table 5. Because of prior information on row and column sums, these methods are called doubly constrained and it is usually not the case that they are automatically consistent. Such methods are used to provide initial estimates of interregional trade flows, which are then adjusted to row and column sums with bi-proportional balancing methods such as RAS.

A simple approach for generating initial values would be to allocate imports from the rest of the country to the regions of origin according to their market share in total interregional exports (except exports of the importing region). Assuming that the effect of trading distance can be ignored, initial interregional trade flows from region r to region s can be estimated as

$$t_i^{rs} = \frac{t_i^{\mathrm{roc}\ s}}{\sum_p t_i^{p\ \mathrm{roc}} - t_i^{s\ \mathrm{roc}}}. \tag{16}$$

With this approach, interregional exports can be seen as a contribution of the regions to a pool of commodities available for interregional purchases. The shares which other regions contribute to this pool are then used to allocate total interregional imports of a specific region to their region of origin.

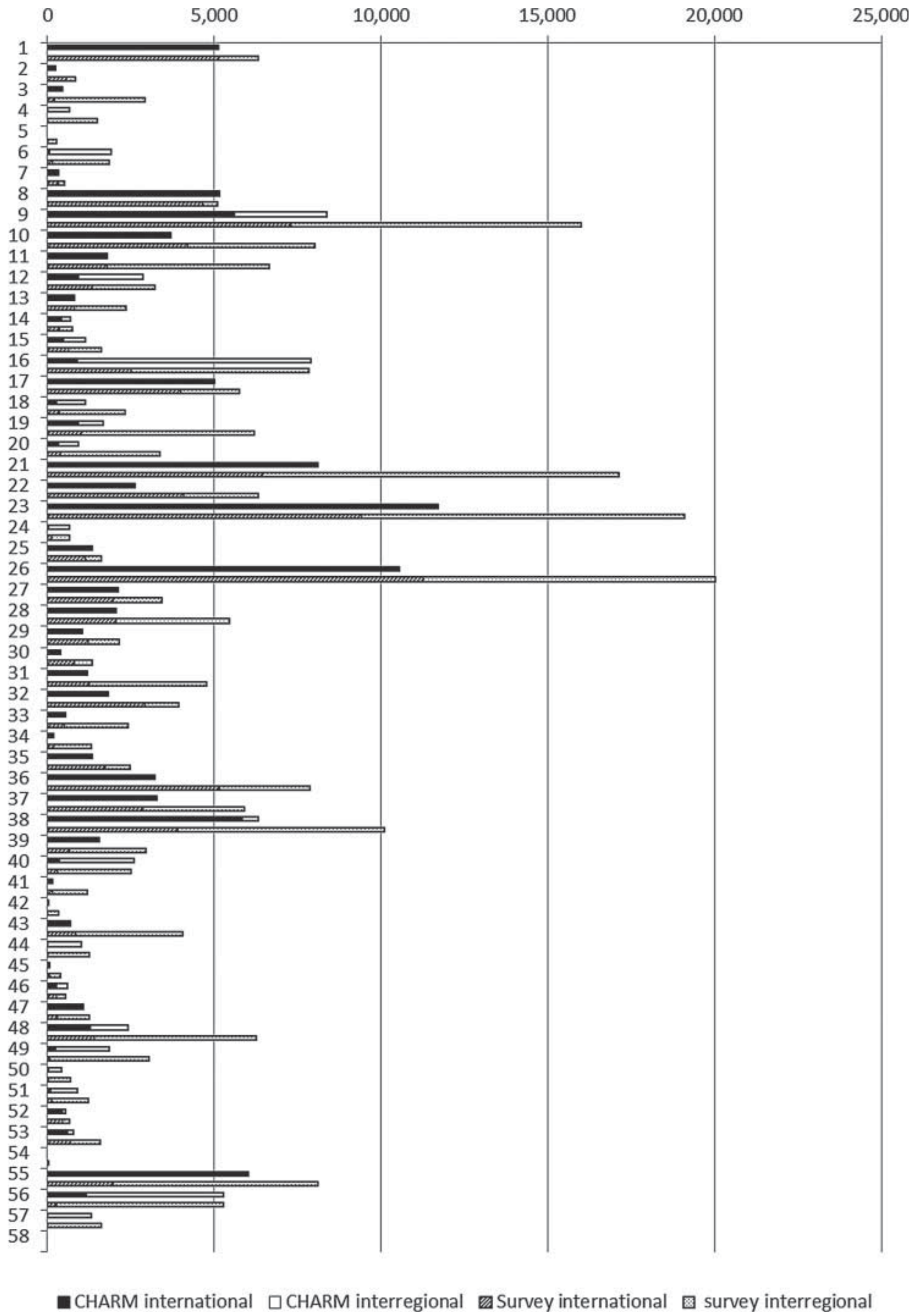
4.3. Case Study of Baden-Württemberg

In this case study of the German state of Baden-Württemberg, an official benchmark IOT for 1991 is first used to illustrate that the original CHARM formula does not estimate cross-hauling in interregional trade. Thereafter, the performance of the modified CHARM formula in estimating cross-hauling in interregional trade is evaluated. In order to isolate errors generated by the estimation procedure of the original CHARM formula and its modified bi-regional version, we use the ‘official’ values for regional output rather than estimating them with regional employment data or some other imprecise measure. The values for intermediate and final demand, as well as gross output for the rest of Germany, are calculated as the residual of national values and those of Baden-Württemberg. With this procedure, errors in the estimation of cross-hauling in interregional trade are not biased by errors made in the estimation of regional output, consumption and foreign trade, which is separate issue. Throughout this section, BW denotes Baden-Württemberg, D denotes Germany (*Deutschland*) and ‘roc’ denotes ‘rest of the country’.

The consequences of applying the original CHARM formula for the estimation of BW’s imports are shown in Figure 1. The figure shows a comparison between CHARM’s estimates of international (light blue) and interregional (light red) imports, as well as international (dark blue) and interregional (dark red) imports from the benchmark table. In total, CHARM delivers positive regional imports even for those sectors with positive trade balances. With conventional non-survey methods such as the CB method, which do not account for cross-hauling, imports in these sectors would have been set to zero, since a positive trade balance indicates that the region is an exporter of the respective product. However, a consideration of individual international and interregional import estimates reveals that, in most sectors, total imports only come from international sources (30 out of 55 sectors with positive imports). The remaining 25 sectors do indeed purchase a certain amount of products from the rest of country, but their interregional exports are assumed to be zero. The reason is that the original CHARM only allocates a certain share of national cross-hauling to the region at hand instead of estimating cross-hauling interregional trade, which is implicitly set to zero, as shown in Section 3. In the benchmark table, however, all sectors with positive total imports purchase a certain amount from the rest of the country, with an average share of 58% of interregional imports in total imports.

Overall, total regional imports (interregional and foreign) are underestimated compared with the survey values. The weighted average percentage error (WAPE) is about -44%. Even so, there are substantial differences in the quality of estimates in terms of individual import estimates: for many sectors, estimates of international imports are close to the survey values, for example, for sector 23 or sector 26, which is indicated by a WAPE of about 4%. The reason why the original CHARM underestimates total imports substantially for those sectors is its poor ability to estimate the interregional part, where the WAPE is about -78%. Thus, it can be concluded that the original CHARM delivers reasonable estimates only for products that are predominantly imported from international sources, for example, sector 8.

FIGURE 1. Interregional and international imports: comparison of CHARM estimates with benchmark values.



For the evaluation of the performance of the modified CHARM in estimating cross-hauling in interregional trade, a distinction is made between two cases. In the first case, it is assumed that regional foreign trade is known, so that the respective values are from the official benchmark table. Thus, regional cross-hauling potential is known as well and deviations of cross-hauling estimates from benchmark data can only result from the inappropriateness of the assumption that the heterogeneity observed in foreign trade of products is identical to that in interregional trade. In the second case, however, regional foreign trade is assumed to be unknown and has to be estimated according to Equations 10a and 10b. This is a situation with which compilers of regional IOT are often confronted, especially when the region is small. The resulting cross-hauling estimates for both cases, as well as their percentage deviation, are shown in Table 6.

First it must be noted that, for most sectors, the differences between cross-hauling estimates in case one and case two are relatively small for most sectors, which indicates that the assumption of foreign imports and exports being proportional to domestic demand or output is appropriate for most products in this case study. Notable exceptions are sectors 14, 15, 16, 17, 24, 25 and 46.

In the estimation of interregional cross-hauling, there are several sectors for which the application of national heterogeneity to interregional trade appears to yield inappropriate interregional cross-hauling shares. For five sectors, 4, 5, 44, 54 and 57, cross-hauling estimates are zero, although benchmark data indicate that there is cross-hauling in interregional trade. The explanation is that there is no cross-hauling in foreign trade, which in turn results in $\tilde{h}_i^n = \tilde{h}_i = 0$ for these sectors. In the case of retail trade, this outcome may be the result of different valuation concepts of foreign imports and exports, as described in Section 3. However, for the remaining cases, the reason is that water and gas supplies, as well as health care and social insurance services, are services provided by the public sector to residents, so that no foreign trade occurs. By contrast, the modified CHARM formula estimates non-zero regional cross-hauling for sector 56, although no cross-hauling is reported in the benchmark data.

Apart from cases where cross-hauling is estimated to be zero, despite a positive amount of cross-hauling being reported in the data or vice versa, the modified CHARM tends to underestimate cross-hauling to a large extent. The WAPE in both cases (50.4% and 51.8%, respectively) indicates that, on average, only half of the interregional cross-hauling reported in the benchmark data is captured with the modified CHARM version. In several sectors, cross-hauling is underestimated by more than 80%, for example, 3, 19 and 20. In comparison, for 2 of the 3 most important sectors for BW's economy, namely 23 and 26, the degree of underestimation is rather low, whereas for 21, the degree of underestimation is moderate compared with the overall outcome. The only sector with an error of less than 10% is 32. Exceptions are 46, 47 and 52, where cross-hauling is overestimated by more than 100%. It should, however, be noted that these sectors are relatively unimportant in terms of interregional trade.

4.4. Discussion

The findings presented above suggest that the modified CHARM produces estimates that are consistent with accounting procedures and that form a useful basis for the construction of MRIO tables. Nevertheless, the estimates are not as accurate as we might wish. One reason for this is the fact that CHARM attributes the existence of cross-hauling

TABLE 6. Comparison of cross-hauling estimates with benchmark data (m. DM).

Sector	Description	Benchmark	Cross-hauling estimates		Deviation (%)	
			Case 1	Case 2	Case 1	Case 2
1	Agriculture	2,410	1,012	1,005	– 58.0	– 58.3
2	Forestry, fishing	558	357	352	– 36.1	– 36.9
3	Electricity, district heat	4,738	324	326	– 93.2	– 93.1
4	Gas supply	1,540	0	0	– 100.0	– 100.0
5	Water supply	542	0	0	– 100.0	– 100.0
6	Coal	0	0	0	0.0	0.0
7	Metal ores, other mining	324	93	91	– 71.3	– 71.8
8	Crude petroleum, Natural gas	0	0	0	0.0	0.0
9	Uranium and thorium ores	11,826	7,107	6,936	– 39.9	– 41.3
10	Refined petroleum	7,666	1,655	1,571	– 78.4	– 79.5
11	Rubber	9,742	2,985	2,921	– 69.4	– 70.0
12	Plastic	1,308	755	780	– 42.3	– 40.4
13	Building materials	3,108	1,397	1,396	– 55.1	– 55.1
14	Ceramic products	354	201	178	– 43.4	– 49.9
15	Glass and glass products	890	519	573	– 41.7	– 35.6
16	Basic iron and steel	560	333	425	– 40.6	– 24.2
17	Non-ferrous metals	2,958	2,349	2,085	– 20.6	– 29.5
18	Casting	2,268	449	441	– 80.2	– 80.5
19	Fabricated metal products	9,156	1,698	1,594	– 81.5	– 82.6
20	Railway locomotives	3,588	533	560	– 85.2	– 84.4
21	Machinery	21,376	11,307	10,705	– 47.1	– 49.9
22	Office and telecom. Equ.	4,432	2,441	2,485	– 44.9	– 43.9
23	Motor vehicles	19,338	15,771	15,218	– 18.4	– 21.3
24	Ships and boats	22	13	9	– 41.6	– 57.4
25	Air and spacecraft	926	1,525	1,224	64.6	32.2
26	Electronic products	17,494	14,032	13,850	– 19.8	– 20.8
27	Optical instruments, clocks	2,924	2,527	2,377	– 13.6	– 18.7
28	Other metal products	6,784	2,946	2,941	– 56.6	– 56.6
29	Musical instr., toys	1,846	912	935	– 50.6	– 49.4
30	Wood	1,108	553	559	– 50.1	– 49.5
31	Wood products	6,844	1,903	1,936	– 72.2	– 71.7
32	Pulp and paper	2,072	1,938	1,963	– 6.5	– 5.3
33	Pulp and paper products	3,832	884	880	– 76.9	– 77.0
34	Publishing and printing	2,270	328	328	– 85.5	– 85.5
35	Leather and leather products	1,542	708	668	– 54.1	– 56.7
36	Textiles	5,438	3,572	3,541	– 34.3	– 34.9
37	Wearing apparel	5,944	1,465	1,353	– 75.3	– 77.2
38	Food products	10,636	6,308	5,910	– 40.7	– 44.4
39	Beverages	3,034	527	515	– 82.6	– 83.0
40	Tobacco	66	40	42	– 39.4	– 36.0
41	Building	2,044	295	295	– 85.6	– 85.5
42	Building completion	620	0	0	– 99.9	– 99.9
43	Wholesale trade, recycling	4,052	1,258	1,293	– 69.0	– 68.1
44	Retail trade	478	0	0	– 100.0	– 100.0
45	Transport via railways	460	126	125	– 72.6	– 72.9
46	Water transport	42	278	133	561.0	215.5
47	Post and telecommunications	366	752	752	105.6	105.5
48	Other transport services	4,696	2,092	2,088	– 55.5	– 55.5

(*Continued*).

TABLE 6. Continued.

Sector	Description	Benchmark	Cross-hauling estimates		Deviation (%)	
			Case 1	Case 2	Case 1	Case 2
49	Financial intermediation	2,374	33	33	– 98.6	– 98.6
50	Insurance	496	82	82	– 83.4	– 83.4
51	Real estate activities	218	159	159	– 27.2	– 27.2
52	Hotels and restaurants	152	837	836	450.7	450.2
53	Science and culture	964	1,106	1,105	14.8	14.7
54	Health and social work	8	0	0	– 100.0	– 100.0
55	Other services	4,252	2,315	2,315	– 45.6	– 45.6
56	Education	0	217	217	Inf	Inf
57	Social security	568	0	0	– 100.0	– 100.0
58	Non-profit org.	0	0	0	0.0	0.0
Total		203,254	101,015	98,108	–	–
WAPE		–	–	–	– 50.4	– 51.8

Source: Own calculation.

solely to the heterogeneity of products. In reality, cross-hauling is also caused by other factors.

One of these factors is the aggregation of products into product groups. For example, if a region exports white wine and imports red wine, we would observe cross-hauling in the product group 'wine'. Theoretically, one could imagine an extremely disaggregated IOT with very narrowly defined product groups. In the case of wine, this would mean that each vintage would be represented as a product group. In such an extremely disaggregated table, there would be very little cross-hauling. In reality, however, that level of disaggregation is simply not possible and cross-hauling will always be present.

Another reason for cross-hauling is the fact that administrative borders and functional economic areas do not always coincide. This problem tends to occur more frequently in relatively small regions. Imagine, for example, a milk farmer and a cheese factory located in the same region. If both of them are located near the borders of the region (one in the East and one in the West), the closest suppliers and customers may be outside the region. The cheese factory may choose to buy milk from outside the region, and the milk farmer may choose to sell milk to a customer outside the region. Milk will be cross-hauled. In a similar fashion, consumers make shopping trips to stores and workers commute to workplaces outside their home region.

Finally, the assumption that $\tilde{h}_i^n = \tilde{h}_i$ may not be entirely realistic if certain products are specific to certain regions. A possible alternative, in order to avoid the assumption of $\tilde{h}_i^n = \tilde{h}_i$, would be to use superior proxy data. For example, regional freight transportation data could be used to estimate the share of cross-hauling in freight flows between a region and the rest of the country. Another potential proxy could be commuting data. Commuting and shopping trips across regional borders can be a substantial source of regional cross-hauling, especially for small regions. As long as $\tilde{h}_i \in [0, 1]$, the use of such proxy information in Equation 14 will generate consistent estimates of interregional trade.

Although CHARM relies on the simplifying assumption mentioned above, its results are nevertheless useful. A recent case study for the Chinese province of Hubei by Flegg et al. (2015) found that CHARM was unsuccessful when they attempted to estimate exports and imports of individual products (or product groups), but “its estimates of supply multipliers were generally more realistic” (p. 21). It was also found that the assumption $h_i^n = h_i^r$ gave accurate results on average, which suggests that this assumption does not yield systematic errors, although the estimates for individual sectors were subject to considerable error.

5. CONCLUSION

Our objectives in this paper were threefold. First, we examined the properties of the CHARM, which was originally designed for deriving single-regional IOT from national tables. It was demonstrated that its original formula requires modification in order to deliver estimates consistent with accounting balances. Furthermore, international and interregional trades must be estimated separately, otherwise cross-hauling in interregional trade is implicitly assumed to be zero. These properties are then addressed by developing a modified formula. This modification ensures consistency of trade estimates with accounting balances, as long as the heterogeneity parameter lies between zero and unity.

In the second part, we demonstrated how CHARM can be used for the compilation of bi- and multi-regional IOT. In this context, the ensured consistency of the modified CHARM formula greatly simplifies the compilation. In the bi-regional case, the need to balance the IOT with methods such as RAS is obviated. If a multi-regional table comprising three or more regions is compiled, CHARM will deliver consistent row and column sums of O–D matrices, which can be used as restrictions for doubly constrained spatial interaction models. In this case, it is only necessary to adjust initial values of interregional trade flows to row and column sums, instead of having to balance the whole IOT.

Finally, the case study with the benchmark table of Baden-Württemberg showed that the application of cross-hauling shares observed in national trade data still underestimates cross-hauling in interregional trade. Even in the case of full information about regional cross-hauling potentials and the trade balances, CHARM was only able to capture roughly half of the actual cross-hauling. This outcome must be attributed to the assumption that the regional cross-hauling shares are equal to the national ones (cf. Flegg et al., 2015). Although the modified CHARM version constitutes an improvement in comparison to the original formulation, it does not completely solve the well-known problems of non-survey methods in general, namely the systematic overestimation of intraregional deliveries and the resulting overestimation of regional multipliers.

Our findings clearly underline the need for additional research efforts in the determination of regional cross-hauling shares in order to improve CHARM’s performance. As the only requirement for consistency in terms of accounting balances of the modified CHARM version is that the heterogeneity parameter lies between zero and unity, CHARM allows the simple insertion of superior proxy information on regional cross-hauling shares, for example, information from transportation statistics. It can, more generally, be concluded that the advantage of CHARM compared with quotient-based non-survey methods is its openness to the insertion of additional superior information at each step of the estimation procedure for a ‘hybrid’ approach. The modifications to the CHARM formula in this paper form the basis for such improvements by ensuring consistency with accounting balances in single-, bi- and multi-regional accounting frameworks.

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