Frankfurt Airport's Impact on Regional and National Employment and Income

- Some New Results Using an Improved Version of the Extended Model for Interregional Input-Output-Analysis -

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Abstract

We develop an interregional version of the standard textbook input-output model, that is extended with respect to the inclusion of the consumption expenditures and income generation process into the endogenous part of the input-output table. We also introduce a new method for deriving a two-region version of an interregional input-output table from original input-output tables for an overall economy and one of its regions. In an empirical assessment of the economic effects of the Frankfurt Airport, the interregional model is successfully employed. It is shown, that the model is capable of reducing the degree of overestimation of economic effects that results from inappropriate use of national input-output tables in the assessment of regional impact effects.

Keywords: Input-Output models, airport impacts, interregional trade impact analysis.

JEL classification: C32, C67, C81, R12, R15, R34.

Contents

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Reinhard Hujer and Stefan Kokot[1]

1. Introduction

One of the biggest and longest lasting political controversies in the history of the Federal Republic of Germany started in the late sixties, when Frankfurt Airport was scheduled for it's first major enlargement since 1955. A huge popular campaign against the construction of the new runway (*Startbahn West*) emerged, mounted by an informal amalgamation of local citizens. Members of environmental groups, residential initiatives, political parties, labor unions, students, churches and others were involved in the protest movement. A focal point of the whole conflict was the trade-off between the benefits to the airport operator and other users of the airport on the one hand and, on the other hand, the economic and ecological costs of the airport extension that would be incurred by the residents of the surrounding region.

In the late seventies and early eighties a huge number of large-scale events took place in the region in protest against the airport extension. While the protests were generally peaceful, the occupation of an area of forest near the airport that was scheduled to be cleared in the course of runway construction, as well as massive police interventions created an atmosphere that became more and more aggressive. Although the persistent opposition of the movement did not prevent the enlargement of the airport in the end, there was at least some consensus on both sides of the dispute that another way of dealing with such issues had to be established in the future.

Thus, when representatives of the airport operating company, FAG, and the biggest German airline, Lufthansa, which uses Frankfurt Airport as its main hub for inter- and transcontinental flights, demanded another enlargement of the airport to meet the

[1] We thank Hartmut Bulwien, Christian Mehlinger, Prof. Dr. Bert Rürup and Thomas Voßkamp as well as the staff at the HLT (Uwe van den Busch, Anja Gauler, Dr. Wendelin Gretz and Frank Padberg) for their close collaboration on this project, Prof. Dr. Reiner Stäglin and all of the participants of the Workshop "Regional Input-Output Analysis" at the HWWA in Hamburg on June, 23 2000 for their valuable comments on the topics of this paper. The usual disclaimer applies.

demand created by the enormous growth of air traffic in the past two decades and based on forecasts of continuously increasing demand in the future, the then prime minister of Hessen, Mr. Hans Eichel, launched a mediation process in 1998. The intention was to clarify, "under which circumstances Frankfurt Airport can help to keep up permanently and enhance the competitiveness of the Rhine-Main region with respect to employment and economic structure, without neglecting the ecological costs imposed on the region."[2] This was to be established in an independent process, without prejudging the issue of whether the airport should be enlarged at all or if so, which of the several possible enlargement schemes should be realized.

The mediation group was originally supposed to be made up of representatives of all parties and pressure groups affected by a possible enlargement of the airport, including various citizens' initiatives and action groups, environmental associations, entrepreneurs, unions, state and local authorities and others. But most of the citizens' initiatives and environmental associations that were invited to participate refused to engage in the mediation process. Their main objection was that the process was neither independent nor neutral, but that there was a very strong bias toward a recommendation in favor of enlarging the airport. It was later decided that the non-participants' seats should be filled with additional representatives of governmental units from the area surrounding the airport.

The mediation group itself consisted of 20 members plus three mediators. The mediation group commissioned a total of 20 expert reports, each covering a specific aspect of one of the three major topics of the mediation process, namely "transportation", "ecology, health and social policy" and "economy", and also conducted a total of 15 public hearings with experts from various fields. All of the expert reports had to go through a quality check by a number of independent experts before they were accepted for publication and used as a basis for the mediation group's final report.[3] When the final report was released in February 2000, it caused considerable public controversy, mainly because of its explicit recommendation to build a new runway south of the existing airport.

While the publication of the final report marked the end of the mediation process, it was by no means the end of the story. A three-day public hearing took place from May 10th –12th in Wiesbaden, where a large number of experts as well as representatives of

2 See Mediationsgruppe Flughafen Frankfurt/Main (2000), p. 7.

3 All of the accepted reports as well as the referees' statements are available for free download from the website of the mediation group (http://www.mediation-flughafen.de).

several action groups and environmental organizations were invited to express their views on the topic before the members of the state parliament of Hessen (*Hessischer Landtag*). This was followed on June 5th by another public hearing of representatives of cities and counties located in the vicinity of the airport. Both hearings were organized by the state parliament of Hessen, the body responsible for making a decision.[4] As yet, political decision makers have been reluctant to follow explicitly the recommendations of the mediation group with respect to the proposed southern runway, although the state government, headed by the new prime minister of Hessen, Roland Koch, is expected to decide in favor of an airport enlargement and a new runway. A final decision on the matter is scheduled for the end of August 2000.

One of the central aspects of the whole debate was the economic significance of the airport for the regional economy. When the airport was enlarged for the first time in the eighties, the supporters of enlargement based their central argument almost exclusively on a study of the economic impacts [FAG (1982)] whose main finding was that each job at the airport site generates roughly two more jobs outside of the airport.[5] The necessity of a new study on the subject was uncontroversial among the members of the mediation group. The present paper is an improved and extended version of the study we delivered to the mediation group in 1999.[6] We present some new results, using the same data set as before, but applying new methods to assess the employment and income effects of Frankfurt Airport.

The remainder of this paper is organized as follows. In section 2 we introduce a new class of extended input-output models that is designed to employ all the information contained in an interregional input-output table more efficiently than previously used models did. We also shed some light on the connection between the different categories of airport impacts as laid out in the previous aviation literature and multiplier effects as defined in the traditional input-output literature. Section 3 describes the basic features of the two original input-output tables we used in this study. We compare the national table for the Federal Republic of Germany with the regional table for Hessen. Furthermore we introduce a convenient method for consistent derivation of an interregional input-output table, which requires only information that is already contained in those two tables. The interregional table consists of two regions, Hessen

[4] Further details on both hearings can be found on the website of the state parliament of Hessen (http://www.landtag.hessen.de/flughafen/anhoerungen.html).

[5] See also Bulwien and Vosskamp (1999), pp. 12-22.

[6] See Hujer and Kokot (1999).

and the Rest of Germany, and is used to assess the regional and national impact of Frankfurt Airport in section 4. The last section contains a brief summary of the main results and concludes the paper.

2. An extended input-output model for interregional tables

2.1. The economic impact of an airport

International airports are entities, that have a central economic meaning for the surrounding region. Apart from their original function as suppliers of aviation services, they also produce goods and services that are more or less tightly connected to their main function. Indeed, airports have become locations for a wide range of businesses, including airlines, freight forwarders, flight catering, fuel services, restaurants, hotels, car rentals, aircraft maintenance services, retail and others. These economic activities are carried out by the airport operating company, airlines and other companies that are located on the airport site. None of these activities can persist without any links to the economic environment outside of the airport site. The companies on the airport typically receive a large range of inputs from entities located in the surrounding region, including intermediate goods and services, capital goods and manpower, which is why airports can have a substantial impact on the regional economy.

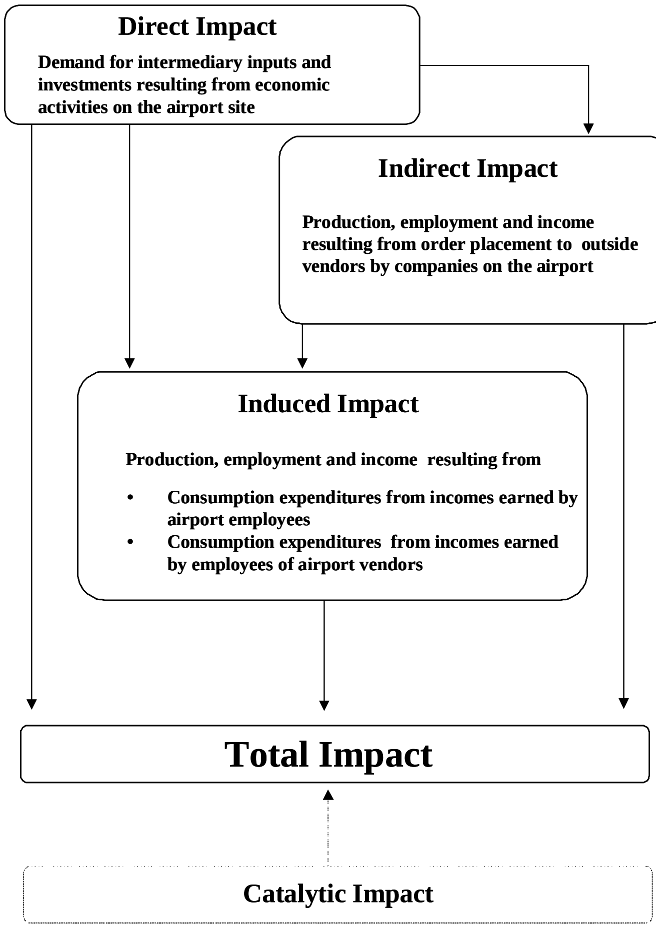
Many of the empirical studies that assess the quantitative impact of airports on the regional economy distinguish four types of economic impacts (see Figure 1):[7]

- *Direct impacts* result from production, income and employment associated with the economic activities located on the airport site.
- *Indirect impacts* are generated in the surrounding economy through the chain of suppliers of goods and services to the direct on-site activities.
- *Induced impacts* result from the expenditure of incomes paid to workers employed on the airport site or in the chain of suppliers.
- *Catalytic impacts* are generated by the attraction, retention or expansion of economic activities within the regional economy as a result of the accessibility to markets due to the airport. The basic assumption here is that many companies

[7] See for example the series of papers on this topic published by the European section of the Airports Council International [ACI (1992, 1993, 1998)].

choose to locate in an area precisely because of its proximity to an international airport.[8]

Figure 1: Economic impacts of an airport



In the aviation literature there are two distinct empirical approaches employed for the analysis of airport impacts, the simple *multiplier method*[9] and the *input-output model*[10]. The starting point in both approaches is an assessment of the direct effects. In many cases, data on employment and value added of the enterprises located on the airport site

8 The quantitative assessment of the catalytic impact of Frankfurt airport on the region has been treated in a separate study by Baum et al. (1999), so our assessment will concentrate only on the direct, indirect and induced impact.

9 Applications of the multiplier model in the aviation context include Schallaböck and Köhn (1997), Kaspar et al. (1992) and FAG (1982).

10 Applications of the input-output model include Baum et al. (1998), Bulwien and Partner (1998a, 1998b), Aring et al. (1996), Hübl et al. (1994), Batey, Madden and Scholefield (1993), Norris and Golaszewski (1990) and Barol (1989).

are regularly collected by the airport operating company. If this is not the case or if the data collected by the operator are not sufficient, surveys have to be conducted.

In the simple *multiplier* framework the initial data have to be accommodated by additional measures that describe the efficiency of the direct effects within the regional or national economy under considerations. These data often stem from the national or regional accounts or have to be estimated from other sources. The method then proceeds to derive multiplier coefficients from the additional data in a rather arbitrary manner, which are used to compute the magnitude of indirect and induced effects on an aggregate level. There are several drawbacks of this approach. Virtually no information on the industrial linkage structure is used. Furthermore, the validity of the outcome can only be justified if some very restrictive assumptions hold.

The *input-output model* in contrast does not rest on such restrictive assumptions, since it employs a type of general equilibrium model of industrial production on a sectoral level that is well embedded in economic theory.[11] The indirect and induced impacts of an airport can be estimated on a disaggregated level, both with respect to the industrial linkage structure and with respect to regional subdivisions. In order to conduct an analysis within this framework a data base that includes the direct effects and an additional input-output table, which are often published by official sources, is required.

2.2. The extended input-output model

The focus of any input-output model is on the exchange of intermediate goods and services among different industries in a regional economy. In a sense the input-output table describes the gross production of goods and services inside an economy that is necessary to produce the level of final demand (i.e. consumption expenditures, investment goods, exports etc.) that is consumed in the period of time under consideration.

In a simple input-output model, all components of the final demand are treated as exogenous, so that e.g. an increase in consumption expenditures increases the intermediate flow of goods and services, but not other components of the final demand. This is a serious limitation, since the additional incomes generated in the production process will at least in part be spent on additional purchases of goods and services, i.e. final demand will increase by more than the initial increase and thus the intermediate

[11] On the origins of input-output analysis see e.g. the collection of papers in Leontief (1986).

production will also need to expand according to this additional demand. We labeled this effect as the "induced impact".

An extended input-output model aims to capture this additional increase in gross production by treating the consumption expenditures as endogenous. There are several ways to incorporate the economic activities of private households into the input-output framework. The standard approach simply includes an additional productive sector in the matrix of technical coefficients $\underline{A}$ and thus treats consumption expenditures as inputs and labor as output of the household sector [see e.g. Miller and Blair (1985)]. There are several extensions of this standard model that disaggregate household activities and include other socio-demographic activities. Typical topics include analysis of unemployment, rural-urban migration or income redistribution on a regional level [see Batey (1985), Hewings and Jensen (1986) and Batey and Weeks (1989)].

The treatment of consumption demand constitutes the major drawback of this approach. Since the ratio of each sector's consumption output to the total consumption output is included in the last column of the matrix $\underline{A}$, these models do take into account the distribution of consumption demand across industries, but do not explicitly consider that part of the total income generated in the production process which is used for private household savings. Typically there is an inherent confusion of marginal and average consumption propensity that is not resolved within this framework.[12]

The approach laid out by Pischner and Stäglin (1976), which forms the basis for our own version of the extended input-output model, is closely related to the models of Miyazawa (1960) and Schumann (1975), since all three papers propose to incorporate a Keynesian consumption function into the standard extended input-output framework[13]. In a sense, it presents a very convenient framework, that lends itself naturally to the kind of empirical application we have in mind. Extensions along these lines that allow

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[12] As Miyazawa (1960), pp. 58-59 put it: "The household sector is accordingly regarded as an industry whose output is labor and whose input are consumption goods, and is treated just as the others are, i.e. it's input-output ratios are assumed constant. But consumers are not a technologically determined production process, but choice making organisms. Furthermore, the factors of choice-making, i.e. the consumption coefficients are not as stable as the input coefficients of the other producing sectors …" His recommendation is to incorporate a Keynesian consumption function into the extended input-output framework.

[13] The model by Miyazawa (1960) additionally incorporates the Keynesian import multiplier in an open economy setting, while Schumann (1975) basically suggests the same model as Pischner and Stäglin in a different notation. The significant difference from Pischner and Stäglin's approach lies in the details of the empirical implementation which is far less demanding in terms of data requirement, since it involves only the estimation of a marginal propensity to consume on the aggregate level. Schumann (1975) instead estimated 14 separate consumption functions for each industry in his table using a time series of 14 yearly input-output tables.

for, say, assessment of the impact of changes in the income distribution or international trade are presented in a interregional and a national setting in Miyazawa (1976).

In a general formulation of the extended input-output model, the gross output impact $\Delta \underline{x}$ of an exogenous change in final demand $\Delta \underline{y}_0$ can be shown to be given by the following expression

$$\Delta \underline{x} = \left\{ (\underline{I} - \underline{A})^{-1} \cdot (\underline{I} - \underline{V})^{-1} \right\} \cdot \Delta \underline{y}_0 ,$$

where $(\underline{I} - \underline{A})^{-1}$ is the Leontief-inverse of the simple static input-output model and $(\underline{I} - \underline{V})^{-1}$ is a matrix of consumption multipliers. The matrix $\underline{V}$ gives the first round effect of $\Delta \underline{y}_0$ in terms of consumption, i.e.

$$\Delta \underline{y}_1 = \underline{V} \cdot \Delta \underline{y}_0 .$$

Pischner and Stäglin (1976) introduced the following decomposition with respect to $\underline{V}$

$$\underline{V} = \underline{c}_s \cdot c_m \cdot \underline{b}' \cdot (\underline{I} - \underline{A})^{-1} .$$

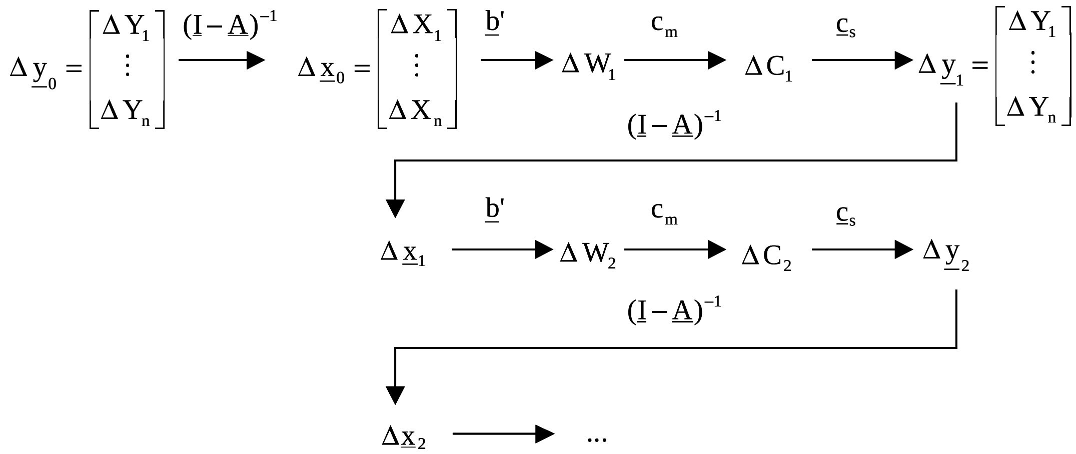
The vector $\underline{b}$ contains the input coefficients for the income generated in each industry, so its typical element is $b_j = W_j / X_j$, with W_j the income distributed to private households (wages and profits) and X_j the gross output of sector j. Premultiplication of $\Delta \underline{y}_0$ by $\underline{b}' \cdot (\underline{I} - \underline{A})^{-1}$ yields a scalar ΔW_0, which is the sum of the first round income changes across all industries in response to $\Delta \underline{y}_0$

$$\Delta W_0 = \underline{b}' \cdot (\underline{I} - \underline{A})^{-1} \cdot \Delta \underline{y}_0 .$$

The corresponding induced change in consumption demand can be computed by multiplying ΔW_0 by a scalar c_m, which is the marginal propensity to consume. The resulting total first round change of consumption expenditures ΔC_0 has to be distributed across the products of all industries. Multiplication of ΔC_0 with a vector $\underline{c}_s$, with typical element c_j given by the proportion of the consumption goods produced by industry j to the total consumption output $c_j = C_j / C$ yields the desired result, a vector of induced first round changes of the consumption demand of private households $\Delta \underline{y}_1$.

With this quantity in hand, we can use the ordinary Leontief inverse to compute the resultant first round impact in terms of gross output $\Delta \underline{x}_1$. This process repeats itself, giving rise to further rounds of production (see Figure 2).

Figure 2 The structure of the extended IO-model according to Pischner and Stäglin (1976)



The total final demand that is created in this process is given by[14]

$$\begin{aligned}\Delta\underline{y}_{total} &= \Delta\underline{y}_0 + \Delta\underline{y}_1 + \Delta\underline{y}_2 + \dots \\ &= \Delta\underline{y}_0 + \underline{V}\cdot\Delta\underline{y}_0 + \underline{V}^2\cdot\Delta\underline{y}_0 + \dots \\ &= \left(\underline{I} + \underline{V} + \underline{V}^2 + \dots\right)\cdot\Delta\underline{y}_0 \\ &= \left(\underline{I} + \underline{V}\right)^{-1}\cdot\Delta\underline{y}_0.\end{aligned}$$

The corresponding gross production $\Delta\underline{x}$ can be calculated by premultiplication of $\Delta\underline{y}_{total}$ by the Leontief inverse

$$\begin{aligned}\Delta\underline{x} &= \left(\underline{I} - A\right)^{-1}\cdot\Delta\underline{y}_{total} \\ &= \left(\underline{I} - A\right)^{-1}\cdot\left(\underline{I} - \underline{V}\right)^{-1}\cdot\Delta\underline{y}_0.\end{aligned}$$

2.3. The extended model in an interregional setting

In order to account for all features of our interregional input-output table, which we describe in section 3 of this paper in detail, we will improve the extended model along the lines of Pischner and Stäglin (1976). Consider analyzing the following input-output table for two regions H (Hessen) and R (Rest of Germany)

$$A^* = \begin{bmatrix} \underline{A}^{H} & \underline{a}^{H\rightarrow R} \\ \underline{a}^{R\rightarrow H} & A^{R} \end{bmatrix},$$

[14] The regularity conditions with respect to the coefficients of $\underline{A}$, that are needed to establish the following results are discussed in the appendix.

where

$\underline{A}^H$	$(n \times n)$-matrix of input coefficients for intermediate commodity flows inside H,
$\underline{a}^{R \to H}$	$(n \times n)$- vector of input coefficients for intermediate commodity flows from R to H,
$\underline{a}^{H \to R}$	$(n \times n)$- vector of input coefficients for intermediate commodity flows from H to R,
A^R	scalar, sum of all input coefficients for intermediate commodity flows inside R.

In this restricted version of an interregional input-output table we observe all the commodity flows involving industries in the H region, whereas the R region consists of only one aggregate industry. Our main goal is to draw inferences on the magnitude of indirect and induced production in the H region, when feedback effects resulting from interregional trade with the R region are being accounted for.

There are two basic features that we incorporate into this setting. First, the associated input-output model should be able to differentiate between incomes that are distributed and accordingly consumed in region H and the corresponding incomes in the other region. Secondly, we observe that part of the consumption expenditures in the H region come directly from the R region. In the input-output table for Hessen 1993, we find that roughly 22.5 % of total consumption in Hessen is produced in the Rest of Germany (direct imports of consumption goods). Thus in addition to the feedback effects resulting from the interregional trade in intermediate commodities, a second channel of feedback effects can be attributed to the interregional direct exchange of consumption goods. Taken together, this means we assume that commodity flows are mobile across regions, while workers and consumers are not.

These features can be incorporated into the extended input-output model through a simple modification of the multiplier matrix $\underline{V}$ for the first round consumption effects, which is now given by

$$\begin{aligned} \Delta \underline{y}_1^* &= \underline{V}^* \cdot \Delta \underline{y}_0 \\ &= \left\{ \underline{C}_s^* \cdot c_m \cdot \underline{T}^* \cdot \underline{B}^* \cdot (\underline{I} - \underline{A}^*)^{-1} \right\} \cdot \Delta \underline{y}_0 . \end{aligned}$$

The matrix of income coefficients $\underline{B}^*$ can be partitioned as follows

$$\underline{B}^* = \left[\begin{array}{ccc:c} b_1 & \cdots & 0 & 0 \\ \vdots & \ddots & \vdots & \vdots \\ 0 & \cdots & b_n & 0 \\ \hdashline 0 & \cdots & 0 & b_R \end{array} \right],$$

where the coefficients $b_1, \ldots, b_n$ are the income coefficients for the H region and b_R is the corresponding coefficient for the R region. Premultiplication of this matrix by the initial production impact of the change in final demand $\Delta \underline{x}_0 = (\underline{I} - \underline{A}^*)^{-1} \cdot \Delta \underline{y}_0$ yields a column vector $\underline{w}$*, which contains the first round income generated in each industry of the H region in his first n rows and the total first round income in the R region in the last row

$$\underline{w}^* = \begin{bmatrix} \Delta W_1 \\ \vdots \\ \Delta W_n \\ \hdashline \Delta W_R \end{bmatrix}.$$

In order to account for the fact, that incomes generated in the H region are being spent on consumption independently of the industry in which they were earned, we have to multiply $\underline{w}$* by the $[(n+1) \times (n+1)]$ transformation matrix $\underline{T}^*$ given by

$$\underline{T}^* = \left[\begin{array}{ccc:c} 1 & \ldots & 1 & 0 \\ \vdots & \ddots & \vdots & \vdots \\ 1 & \ldots & 1 & 0 \\ \hdashline 0 & \ldots & 0 & 1 \end{array}\right],$$

and thus end up with a column vector $\underline{w}$**, having the total first round income earned in the H region as it's first n rows and the total first round income earned in the R region in its last row

$$\underline{w}^{**} = \begin{bmatrix} \sum_{i=1}^{n} \Delta W_i \\ \vdots \\ \sum_{i=1}^{n} \Delta W_i \\ \hdashline \Delta W_R \end{bmatrix}.$$

Multiplication of $\underline{w}^{**}$ by the marginal consumption propensity c_m yields the following vector of aggregate first round additional consumption demand in both regions

$$\underline{c}^* = \begin{bmatrix} \sum_{i=1}^{n} \Delta C_i \\ \vdots \\ \sum_{i=1}^{n} \Delta C_i \\ \hdashline \Delta C_R \end{bmatrix}$$

The last step in the computation of the first round effects involves premultiplication of the consumption vector by the matrix $\underline{C}_s^*$, which contains the modified consumption structure for the interregional IO-table, and is given by

$$\underline{C}_s^* = \left[\begin{array}{ccc:c} c_{H,1} & \cdots & 0 & c_{H\to R,1} \\ \vdots & \ddots & \vdots & \vdots \\ 0 & \cdots & c_{H,n} & c_{H\to R,n} \\ \hdashline c_{R\to H,1} & \cdots & c_{R\to H,n} & c_R \end{array}\right],$$

where

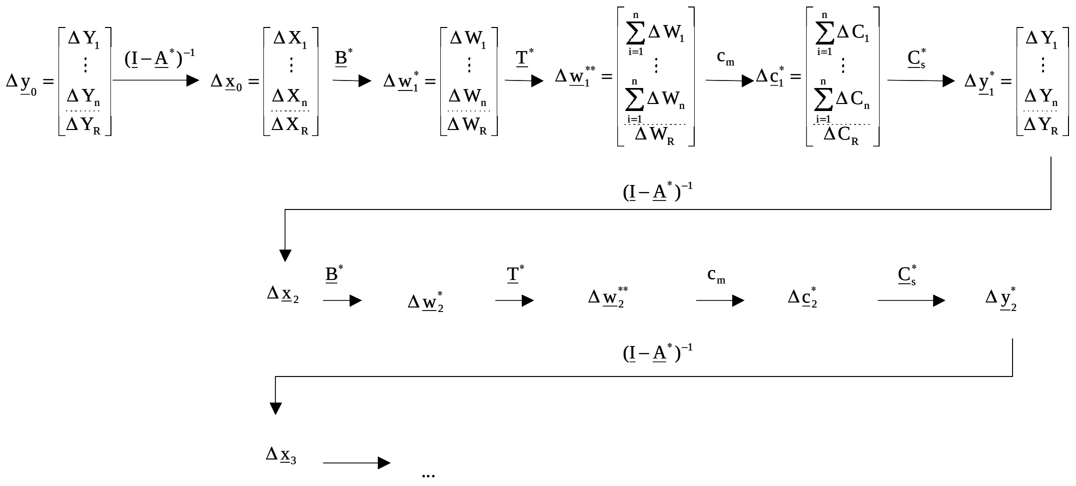
$c_{H,i}$	proportion of the total consumption in the H region that is produced by sector i in region H,
$c_{R\to H,i}$	proportion of the total consumption in the H region that is produced by sector i in the R region,
$c_{H\to R,i}$	proportion of the total consumption in the R region that is produced by sector i in region H,
c_R	proportion of the total consumption in the R region that is produced in region R.

The result of this operation yields a vector $\Delta \underline{y}_1^*$ whose elements contain the additional commodities in terms of final demand that each of the n sectors in region H and the aggregate industry of region R have to produce in order to satisfy the additional first round demand given by $\underline{c}^*$

$$\Delta \underline{y}_1^* = \begin{bmatrix} \Delta Y_1 \\ \vdots \\ \Delta Y_n \\ \hdashline \Delta Y_R \end{bmatrix}.$$

The structure of the improved model is summarized in Figure 3.

Figure 3 The structure of the extended interregional model



The corresponding total gross production $\Delta \underline{x}$ can be calculated using

$$\Delta \underline{x} = \left\{(\underline{I} - \underline{A}^{*})^{-1} \cdot (\underline{I} - \underline{V}^{*})^{-1}\right\} \cdot \Delta \underline{y}_0 .$$

This vector contains the total additional gross production in the H region in his first n rows and in the R region in the last row that is necessary to satisfy the additional demand $\Delta \underline{y}_0$

$$\Delta \underline{x} = \begin{bmatrix} \Delta x_1 \\ \vdots \\ \Delta x_n \\ \hdashline \Delta x_R \end{bmatrix}.$$

2.4. Indirect and induced multipliers in the interregional framework

In order to differentiate between indirect and induced impact as defined in the aviation literature we will now clarify the relation between the production multipliers derived in the two previous sections and the categories of economic impacts mentioned in section 2.1.[15] Before doing so, let us discuss the basic assumption, that is inherent to our study. We view the airport as an entity that is *exogenous* to the economy of the surrounding region and want to assess the consequences for regional employment and income if the

[15] As Batey, Madden and Scholefield (1993) observed, there is a discrepancy between the usage of the terms “indirect effects” and “induced effects” in the traditional input-output literature and in the aviation literature. In input-output analysis the term *indirect effects* is reserved for the first round effects of an exogenous change in final demand, while *induced effects* refer to the remaining production necessary to satisfy the additional demand. It can be calculated by the difference of the total effect in the extended model and the first round effect.

airport were to be completely removed. Therefore we extract the airport from the industrial interaction part of the input-output table in order to avoid the kind of problems of double counting and the interpretation of direct, indirect and induced multipliers that have been addressed in the influential study by West and Jensen (1980).

The key point to notice in our study design is that all inputs that airport enterprises receive are final demands from the viewpoint of the regional economy *but* at the same time they represent part of the *total gross production* in the regional economy. Therefore, although the multipliers presented do indeed include the *initial effect* as defined by West and Jensen (1980), there is no double counting involved, since these are precisely the effects we aim to draw inferences on. Apart from the production, employment and associated income that is generated *on the airport site* (these quantities constitute our direct impact), the basic question of our study is: What would be the implication of "tearing out the airport" from its current location *for the local economy of the surrounding region* when there are *no alternative uses* for the resources that depend in one way or another on the airport?

Indirect impact effects are derived using the simple static input-output model. Enterprises located on the airport site receive commodities from suppliers outside and use them either as intermediate inputs or to add to their capital stock. Since we treat the whole airport as an exogenous entity, these commodity flows constitute additional final demand with respect to the region in which it is located. The indirect production impact is given by[16]

$$\Delta \underline{x}_{\text{indirect}} = \left\{ (\underline{I} - \underline{A})^{-1} \right\} \cdot \Delta\, \underline{y}\,.$$

In order to assess employment effects we premultiply the vector of additional indirect production $\Delta \underline{x}_{\text{indirect}}$ by the diagonal matrix of labor coefficients $\underline{AK}$

$$\underline{AK} = \begin{bmatrix} \frac{E_1}{X_1} & \cdots & 0 \\ \vdots & \ddots & \vdots \\ 0 & \cdots & \frac{E_n}{X_n} \end{bmatrix},$$

where E_j is the number of workers employed in sector j and X_j is the gross output produced by sector j. Income effects can be evaluated by pre-multiplying $\Delta \underline{x}_{\text{indirect}}$ with

[16] In order to lessen the notational burden, we only give the expressions for the Pischner and Stäglin model in this section. It should be clear that completely analogous expressions can be derived for the interregional model.

the diagonal matrix $\underline{B}$, having sectoral income coefficients as diagonal elements. Thus, the vectors containing indirect employment or income effects are given by

$$\Delta \underline{e}_{indirect} = \left\{ \underline{AK} \cdot (\underline{I} - \underline{A})^{-1} \right\} \cdot \Delta \underline{y}$$
$$\Delta \underline{w}_{indirect} = \left\{ \underline{B} \cdot (\underline{I} - \underline{A})^{-1} \right\} \cdot \Delta \underline{y}.$$

In order to derive the induced impact effects, we distinguish between two sources of exogenous demand generated by the airport. The *induced impact from direct incomes* is generated by the consumption expenditures that result from the incomes earned by employees on the airport. On the other hand, we have the *induced impact from indirect incomes* which result from commodity flows that airport enterprises received from suppliers outside.

In order to calculate the induced multiplier effects with respect to the direct incomes, we start with the sum of wages and salaries earned by airport employees which we know from our survey and multiply them by the marginal consumption propensity c_m and the vector of sectoral consumption coefficients $\underline{c}_s$. This operation yields a vector of sectoral final demands $\Delta \underline{y}_{dir}$. The total gross production effect is then given by

$$\Delta \underline{x}_{induced}^{dir} = \left\{ (\underline{I} - \underline{A})^{-1} \cdot (\underline{I} - \underline{V})^{-1} \right\} \cdot \Delta \underline{y}_{dir} .$$

With respect to the induced effects from indirect incomes, we use exactly the same survey data on intermediate commodity flows and investments that formed the initial effects for the indirect impact. In order to avoid double counting we have to subtract indirect effects, so

$$\Delta \underline{x}_{induced}^{ind} = \left\{ (\underline{I} - \underline{A})^{-1} \cdot [(\underline{I} - \underline{V})^{-1} - \underline{I}] \right\} \cdot \Delta \underline{y}_{ind} .$$

Total induced impact $\Delta \underline{x}_{induced}$ is given by the sum of the partial effects

$$\Delta \underline{x}_{induced} = \Delta \underline{x}_{induced}^{dir} + \Delta \underline{x}_{induced}^{ind} .$$

The associated employment and income effects can again be calculated using the coefficient matrices $\underline{AK}$ and $\underline{B}$

$$\Delta \underline{e}_{induced} = \underline{AK} \cdot \Delta \underline{x}_{induced}$$
$$\Delta \underline{w}_{induced} = \underline{B} \cdot \Delta \underline{x}_{induced} .$$

In order to summarize our results we use the following definitions for employment and income multipliers. These multipliers have been used extensively in previous airport studies, probably with the intention of reducing the dimensionality of the results by summing the outcome variable over all sectors. The *employment multiplier* is defined as

$$m^E = \frac{(\text{indirect employment} + \text{induced employment})}{\text{direct employment}}.$$

This multiplier tells us, how many additional workers are being employed in the surrounding areas of the airport per worker employed on the airport site. The *income multiplier* is defined analogously as

$$m^W = \frac{(\text{indirect income} + \text{induced income})}{\text{direct income}}.$$

Thus, the income multiplier gives the additional income that is earned in the surrounding area per unit of income earned by employees on the airport site.

3. The interregional input-output table

3.1. The original input-output tables for Germany and Hessen

We use two different input-output tables in this study. A national input-output table for Germany as a whole for 1992 published by the Federal Statistical Office of Germany[17] is used to assess economic impacts on the overall economy. We also needed data from this table in order to derive the interregional input-output table. In order to assess impacts on the regional and interregional level we used a regional input-output table compiled by the HLT[18] describing the industrial linkage structure in Hessen 1993.

The input-output table for Germany is based on the functional principle and originally distinguished between 58 industries. The input-output table for Hessen originally included 18 industries[19]. Because Frankfurt Airport accounts for about 73.5% of the gross production of the sector "Remaining Transportation"[20] we excluded this sector from the interindustrial linkage part of the Hessen table in order to avoid double counting. Thus, we ended up with a 17 sector input-output table for Hessen, and therefore aggregated the national table as well. The definition of industries in this 17

[17] See Statistisches Bundesamt (1997).

[18] The HLT Gesellschaft für Forschung, Planung, Entwicklung mbH is a partly state owned research, planning and development institution which advises state, regional and local administration as well as private enterprises, and has substantial experience in the conduct of regional input-output analysis. See Gretz-Roth (1989).

[19] See section 6.2. in Hujer and Kokot (1999) for more details on the derivation of the input-output table for Hessen.

[20] Hessen also has a number of minor amateur and military airfields, but Frankfurt Airport is its only regular commercial airport.

sector scheme, as well as the original identification numbers from the 58 sector scheme can be inferred from Table 1.

Table 1 Definition of sectors in the regional and the national input-output table

Number Hessen	Number Germany	Industry
1	1-2	Agriculture and fisheries
2	3-15	Coal, gas, electric power, water, chemicals, rubber, stone, clay and glass products, ceramics/pottery, products of petroleum and coal
3	16-19	Primary metals
4	21-22; 26-27	Mechanical engineering, data processing and office equipments, electrical machinery, precision engineering
5	20, 23-25	Motor vehicles
6	28-29	Fabricated metal products, musical instruments, toys, jewelry
7	30-37	Lumber and wood products, paper and allied products, printing, leather, textile mill products, apparel
8	38-40	Food and kindred products, tobacco
9	41-42	New construction and maintenance
10	43-44	Trade
11	45-47	Transportation, communications
12	49, 50	Banking, finance, insurance
13	51	Real estate and rentals
14	52	Catering trade
15	53, 54	Culture, health
16	55	Other market services (e.g. consultations, planing, cleaning, laundries)
17	56-58	Central, regional and local governmental units, social insurance, non-profit organizations

In a comparison of the national and the regional input-output tables, the first thing to notice is that since regional commodity flows are also contained in the national table, the regional inputs in absolute terms as well as the input coefficients are usually much smaller than the corresponding figures on the national level. In Table 2 we exemplify this using the figures for the sector "Primary metals". In the regional table roughly 16 % of all inputs come from industries located in the same region, while 20 % come from industries located in other parts of Germany and another 21 % are delivered from foreign suppliers; evidently, this industry exhibits a high degree of direct import dependency. The corresponding figures from the national table reveal a different picture. Here the metal industry receives 61 % of its inputs from domestic suppliers and the import quota is only 9 %. In other words, the percentage of imports is roughly four times higher in the regional table while the proportion of domestic inputs is only about one sixth of the national figure.

Table 2 Inputs received by the sector "Primary metals"

Sector	Excerpt from regional IO-table for Hessen			Excerpt from national IO-table for Germany		
	Intermediate inputs	Input coefficients	Production multipliers	Intermediate inputs	Input coefficients	Production multipliers
Agriculture and fisheries	0.5	0.0000	0.0008	13.0	0.0001	0.0026
....	...	...	...	...	...	...
Culture, health	26.3	0.0042	0.0070	539.0	0.0033	0.0129
Other market services	336.9	0.0536	0.0787	10 904.0	0.0663	0.1739
Governmental units, non-profit organizations	6.2	0.0010	0.0020	940.0	0.0057	0.0160
Sum:	1 030.8	0.1641	1.2182	100 990.0	0.6136	2.2029
Imports from foreign countries	1 373.6	0.2187	-	15 375.0	0.0934	-
Imports from other states in Germany	1 279.3	0.2037	-	-	-	-
Gross value added	2 597.0	0.4135	-	48 212.0	0.2929	-
Gross output	6 280.7	1.0000	-	164 577.0	1.0000	-

Millions of DM. Source: Statistisches Bundesamt, Fachserie 18, Reihe 2, HLT, own calculations.

The discrepancies in terms of the ordinary production multipliers do in part reflect the non-congruency between the regional and the national table. For the "Primary metals"-industry the column sum of the ordinary multipliers is 1.8 times higher when the national table is used to calculate the Leontief inverse.[21] As can be seen from the following Table 3, these differences between the regional and the national table prevail with respect to all sectors.

[21] The j-th column sum of the Leontief inverse gives the total additional production requirement in all industries, in order for the j-th sector to deliver an additional unit to final demand.

Table 3 Sectoral output multipliers

Sector	Sum (across columns) of production multipliers		Ratio Hessen to Germany
	Hessen	Germany	in %
Agriculture and fisheries	1.2939	1.8852	68.6
Coal, Gas, electric power, ...	1.2646	1.8059	70.0
Primary metals	1.2182	2.2029	55.3
Mechanical engineering, ...	1.2853	1.8606	69.1
Motor vehicles	1.2722	2.0634	61.7
Fabricated metal products, ...	1.3079	1.8263	71.6
Lumber and wood products, ...	1.3144	1.8815	69.9
Food and kindred products, tobacco	1.4318	2.0570	69.6
New construction and maintenance	1.3622	1.8574	73.3
Trade	1.3368	1.4750	90.6
Transportation, communications	1.2902	1.6362	78.9
Banking, finance, insurance	1.8973	3.3475	56.7
Real estate and rentals	1.3262	1.4046	94.4
Catering trade	1.4278	1.9022	75.1
Culture, health	1.3850	1.6716	82.9
Other market services	1.3840	1.5566	88.9
Governmental units, ...	1.4795	1.7268	85.7
Sum	23.2774	32.1607	72.4

Source: Statistisches Bundesamt, Fachserie 18, Reihe 2, HLT, own calculations.

Another important, distinctive feature of the regional table is the entry of a row of imports from and a column of exports to other regions in Germany, for which there is no counterpart in the national table. As is well known from the paper by Gillen and Guccione (1980), the maximum percentage error in terms of gross output that occurs when feedback effects from interregional trade are neglected is inversely related to the degree of a region's self-sufficiency.

From the regional input-output table for Hessen the total proportion of intermediate inputs received from the Rest of Germany amounts to 12.5%, while the exports delivered to the Rest of Germany make up no less than 26.1% of the gross production in Hessen. The interregional trade coefficients for some of the sectors are even higher, as can bee seen from Table 4. Note that the column "outflows from Hessen" includes intermediate goods as well as components of final demand, while the inflows column contains only intermediate goods. We will explain our method for dividing the outflows column into intermediate exports and consumption in the next section.

Table 4 Interregional trade flows (proportion of gross production)

Sector	Inflows to Hessen	Outflows from Hessen
Agriculture and fisheries	21.43%	25.97%
Coal, gas, electric power, ...	21.43%	47.87%
Primary metals	20.37%	44.50%
Mechanical engineering, ...	25.68%	43.58%
Motor vehicles	42.80%	56.83%
Fabricated metal products, ...	17.90%	49.49%
Lumber and wood products, ...	22.55%	51.26%
Food and kindred products, tobacco	20.42%	41.72%
New construction and maintenance	12.74%	3.45%
Trade	3.34%	15.15%
Transportation, communications	7.41%	39.10%
Banking, finance, insurance	1.07%	41.72%
Real estate and rentals	1.47%	0.00%
Catering trade	20.79%	0.00%
Culture, health	10.38%	7.45%
Other market services	5.36%	24.55%
Governmental units, ...	6.34%	0.00%
All Sectors	12.51%	26.01%

Source: HLT, own calculations.

Thus, we may conclude that neglecting feedback effects from interregional trade inside of Germany may lead to a severe bias in the context of this study. Since Hessen is a net exporter of goods and services on the aggregate level, neglecting these feedbacks would probably lead to an underestimation of the regional production effects.

3.2. Derivation of the interregional input-output table

In order to assess feedback effects across regions we compile an interregional input-output table from the tables in hand. The industrial interdependence structure in an interregional input-output table for 2 regions and n industries in each region is given by[22]:

$$\underline{X}^{MR} = \begin{bmatrix} \underline{X}^{H} & \vdots & \underline{M}^{H\to R} \\ \cdots & & \cdots \\ \underline{M}^{R\to H} & \vdots & \underline{X}^{R} \end{bmatrix}$$

where

$\underline{X}^{H}$	$(n \times n)$-matrix of intermediate input flows inside of Hessen,
$\underline{M}^{R\to H}$	$(n \times n)$-matrix of intermediate input flows from the Rest of Germany to Hessen,
$\underline{X}^{R}$	$(n \times n)$-matrix of intermediate input flows inside the Rest of Germany,
$\underline{M}^{H\to R}$	$(n \times n)$-matrix of intermediate input flows from Hessen to the Rest of Germany.

From our original data consisting of the input-output tables for Hessen and for Germany we can identify the following quantities

$\underline{X}^{H}$	intermediate input flows in Hessen, as well as final demand and primary inputs,
$\underline{X}^{B}$	intermediate input flows in Germany, as well as final demand and primary inputs,
$\underline{m}_{\bullet j}^{R\to H}$	a vector containing the column sums of the matrix $\underline{M}^{R\to H}$,
$\underline{m}_{\bullet i}^{H\to R}$	a vector containing all transaction flows from industries in Hessen to the Rest of Germany, without any indication of the absorbing entity (industry, private households, governmental units).

With respect to the decomposition of $\underline{m}_{\bullet i}^{H\to R}$ we assume, that the proportion of each category of final demand and intermediate outputs delivered to industries in the Rest of Germany is equal to the proportion of the corresponding category to the total output minus exports for each sector in Hessen[23]. A preliminary input-output table for the Rest

[22] In regional IO-modeling we typically distinguish between the *interregional* approach along the lines of Isard (1951) and the *multiregional* approach suggested by Cherney (1953) and Moses (1955), which is usually far less demanding in terms of the data required to put up the trading part of the IO-table. Nevertheless, we will derive a variant of the Isaard (1951) table in this section. See Hewings and Jensen (1986) for an overview.

[23] Assume for simplicity's sake that total output consists of three components, intermediate inputs (I), consumption (C) and exports (E); the consumption component of exports would thus be equal to $\frac{C}{(X-E)} \cdot E$, so the ratio of consumption goods to exports would be the same as the ratio of total consumption goods (domestic plus exports) to total output in each sector.

of Germany can be obtained from the original tables for Hessen $\underline{X}^H$ and Germany $\underline{X}^B$ as follows

$$\underline{X}^* = \underline{X}^B - \underline{X}^H.$$

Its elements x_{ij}^* are given by

x_{ij}^B	$\Leftrightarrow$	intermediate commodity flows from sector i to sector j inside Germany consisting of • input flows from Hessen to Hessen • input flows from the Rest of Germany to Hessen • input flows from Hessen to the Rest of Germany • input flows from the Rest of Germany to the Rest of Germany
$- x_{ij}^H$	$\Leftrightarrow$	intermediate commodity flows from sector i to sector j inside Hessen consisting of: • input flows from Hessen to Hessen
$= x_{ij}^*$	$\Leftrightarrow$	intermediate commodity flows from sector i to sector j outside of Hessen including inputs received from and delivered to industries inside of Hessen: • input flows from the Rest of Germany to Hessen • input flows from Hessen to the Rest of Germany • input flows from the Rest of Germany to the Rest of Germany

By computing the preliminary input table for the Rest of Germany $\underline{X}^*$ we can eliminate only transaction flows inside of Hessen, but not the intermediate input flows between the two regions. Without detailed information on the inter-industrial import structure, these commodity flows can be eliminated if we take the Rest of Germany as a whole to be one additional industry, i.e. if we aim to compute the elements of the following matrix:

$$\underline{X}^{MR*} = \begin{bmatrix} \underline{X}^H & \underline{m}_{\bullet i}^{H\rightarrow R} \\ \underline{m}_{\bullet j}^{R\rightarrow H} & X^R \end{bmatrix},$$

where X^R is a scalar equal to the sum of all inter-industrial commodity flows in the Rest of Germany. X^R can be computed as follows

$\sum_i \sum_j x_{ij}^*$	$\Leftrightarrow$	sum of all • input flows inside of the Rest of Germany • input flows from Rest-Germany to Hessen • input flows from Hessen to the Rest of Germany
$- \sum_j m_{\bullet j}^{R\rightarrow H}$	$\Leftrightarrow$	• sum of all inputs received by industries in Hessen from industries in the Rest of Germany
$- \sum_i m_{\bullet i}^{H\rightarrow R}$	$\Leftrightarrow$	• sum of all inputs received by industries in the Rest of Germany from industries in Hessen
$= X^R$	$\Leftrightarrow$	• sum of all input flows inside of the Rest of Germany

The matrix of primary inputs for the interregional input-output table $\underline{PI}^R$ can be derived from the original tables as follows

$$\underline{PI}^R = \underline{PI}^B - \underline{PI}^H.$$

Given the absence of any valuable information on the import-export structure of primary inputs, we assume that there is no direct exchange of primary inputs between Hessen and the Rest of Germany. Since we will need only incomes distributed to private households (i.e. wages, salaries and profits), this assumption is restrictive with regard to our purposes only if the balance of transfer payments between Hessen and entities in other states in Germany is significantly different from zero for these categories of income.

The gross value added for the Rest of Germany can thus be calculated as the difference between the corresponding figures for Germany and Hessen

$$\sum_i GWO_i^R = \sum_i GWO_i^B - \sum_i GWO_i^H .$$

The gross output of the industry "Rest of Germany" is equal to

$\sum_j m_{\bullet j}^{R\to H}$	$\Leftrightarrow$	• sum of all inputs received by industries in Hessen from industries in the Rest of Germany"
$+ X^R$	$\Leftrightarrow$	• sum of all input flows inside of the Rest of Germany
$+ \sum_i GWO_i^R$	$\Leftrightarrow$	• sum of the gross value added of all industries in the Rest of Germany
$= \sum_i GO_i^R$	$\Leftrightarrow$	• sum of the gross outputs of all industries in the Rest of Germany

Additional computations have to be conducted in order to obtain the sectoral structure of consumption, wages and salaries as well as the number of employees for the interregional input-output table. These quantities have been derived in analogy to primary and intermediate inputs. Because we do not have any valuable information on the sectoral structure of the direct consumption import flows from the R region to the H region, we will distribute the total proportion of consumption imports $c_{R\to H}$ evenly among all sectors according to

$$c_{R\to H,i} = \frac{1}{n} \cdot c_{R\to H} .$$

With respect to the coefficients for the direct consumption commodity flows from the H region to the R region we assume that the proportion of each sector's consumption exports to its total exports is equal to the proportion of consumption to gross production minus exports of the same sector in Hessen. Thus, we have

$$c_{H\to R,i} = \frac{C_i}{\left(X_i - EX_{H\to R,i}\right)} \cdot \frac{EX_{H\to R,i}}{C_R},$$

where $EX_{H \rightarrow R,i}$ denotes the total exports of sector i in Hessen delivered to the Rest of Germany and C_R is equal to the total consumption demand in the Rest of Germany.

4. Empirical results

4.1. Survey results

In addition to the input-output tables, we used other data in this study that stem from a multitude of sources. In order to gather information on the final demand that is attributable to economic activities located on the airport site and is effective on the regional and national level we conducted a survey of 127 enterprises located on the Rhine-Main airport in Frankfurt am Main (March – May 1999). These enterprises represent about 93% of the total employment at the airport. In our survey we gathered data necessary for the conduct of the input-output analysis, such as employment, gross income of employees, capital goods and intermediate inputs received from suppliers outside of the airport as well as other descriptive information.[24] In order to make the input-output terminology operational to the persons we asked, we defined our key variables in terms of commercial balance sheet positions, as laid out in Table 5.

Table 5 Definition of the variables in the survey

Variable	Definition
Investments	Increase of physical capital stock.[a]
Operating Expenses	Cash drain or increment of liabilities for commodities and services due to regular operation.[b]
Employment	Employees[c] deployed on the airport site.
Income	Gross wages and salaries of employees (including employer's contributions to social insurance systems).[d]

a The capital stock consists of the following items of the commercial balance sheet (see German Commercial Code (HGB), Paragraph 266): II. Tangible assets, including II.1 land, buildings and leasehold rights, II.2 plant and machinery, II.3 other fixtures and fittings, tools and equipment, II.4 payments on account and tangible assets in course of construction.

b Operating expenses consist of the following items of the profit and loss account (see German Commercial Code (HGB), Paragraph 275): 5) Raw materials including 5a) expired costs of raw materials and supplies, 5b) expired costs of acquired merchandise, 8) other operating expenses.

c Including owners, self-employed, temporary employees, permanent work performance contracts, "seemingly self-employed workers".

d Income consists of the following items of the profit and loss account (see German Commercial Code (HGB), Paragraph 275): 6) Staff costs including 6a) wages and salaries, 6b) social security costs and costs related to pension funding.

In addition we used data from the system of national accounts on labor productivity, price indices, private consumption expenditures, disposable income etc. Initial effects were collected separately for each sector and differentiated with respect to the regional location of suppliers[25] and, since the data were collected for the year 1998, we had to deflate the data using sectoral price indices.

Table 6 Initial effects from our survey data

Sector	Operating expenses	Investments	Sum	Suppliers located in region ...			
				Airport	Hessen	Germany	Other
Agriculture and fisheries	0	0	0	-	0	0	-
Coal, gas, electric power, ...	475	0	475	40	242	434	1
Primary metals	3	10	13	-	11	12	0
Mechanical engineering, data processing ...	423	146	570	4	422	556	10
Motor vehicles	667	66	733	-	229	592	141
Fabricated metal products, ...	5	0	5	-	5	5	0
Lumber and wood products, ...	216	28	244	0	77	243	1
Food and kindred products, tobacco	400	-	400	1	322	397	2
New construction and maintenance	254	424	678	1	603	677	-
Trade	3	1	4	-	2	4	0
Transportation, communications	2 954	6	2 960	1 163	1 478	1 792	5
Banking, finance, insurance	17	-	17	0	12	17	-
Real estate and rentals	323	2	326	227	97	98	-
Catering trade	20	0	20	10	10	10	-
Culture, health	0	-	0	0	0	0	-
Other market services	623	0	623	54	383	566	4
Governmental units, ...	1	-	1	-	1	1	-
Sum	6 385	684	7 069	1 500	3 893	5 405	164

0 = less than 0.5. „-“ = no inputs received. Final demand of working stations on the airport site. Millions of DM in 1993 prices.

24 See Rürup and Mehlinger (1999) for details.

25 In the questionnaire we defined a total of 7 sub-regions and raised data on the regional dispersion with respect to this classification. The figures for Hessen and for Germany arise through aggregation of the corresponding sub-regions. See appendix A2 for more details.

The results in Table 6 show, that the largest contribution to the initial effects comes from the sector "Transportation and communication", mostly in terms of operating expenses. Almost one half of the total inputs of this sector come from enterprises that are located at the airport as well, thus disqualifying them from being used in the input-output analysis as final demand of the airport in the surrounding area. The sector with the highest proportion (about 70 %) of inputs received from suppliers on the airport site is the sector "Real estate and rentals". These consist mostly of rents paid to the airport company.

The most important sector in terms of investment demand is the sector "New construction and maintenance", which receives almost 90 % of its inputs from suppliers in Hessen. Further important contributions come from the sectors "Mechanical engineering, ..." and "Motor vehicles". These three industries make up for about 93 % of all investment goods received by enterprises on the airport site. We used the column headed "Hessen" as the vector of initial final demand in the regional model, which had to be accommodated by the difference between the sums of the "Germany" and the “Hessen” columns in the interregional model. For the impact assessment using the national input-output table, we used the sum of the “Germany” column as initial effects.

Table 7 Regional income and residential distribution of airport employees

Region	Gross income	Number of airport employees living in region
Frankfurt airport	-	-
Municipal area Frankfurt, surrounding countryside in Hessen close to airport	2 354	36 681
Distant surrounding countryside in Hessen	707	11 010
Rest of Hessen	369	5 752
Surrounding countryside outside of Hessen	363	5 651
Rest of Germany	190	2 958
Foreign countries	-	-
Hessen	3 430	53 444
Germany	3 982	62 053

Gross income of on site employees. Millions of DM in 1993 prices.

In Table 7 we reproduce the regional distribution of the gross incomes earned by airport employees and of their places of residence. Because a direct investigation would probably have led to a high proportion of answer refusals due to data privacy protection and costly data acquisition, we estimated these figures on a firm-by-firm level using the regional distribution of employee's places of residence and the total gross wages and salaries paid as inputs. Multiplying the proportion of employees of company j residing in the i-th region by the gross wages and salaries paid by company j we calculated firm-specific estimates for all regions. Aggregating these estimates over all companies on the airport site yields the regional income distribution contained in the above table.[26]

4.2. Estimation of the consumption function

In order to get an estimate of the marginal propensity to consume, we estimated an aggregate consumption function, using quarterly, deseasonalized data from the national accounts for the period first quarter 1970 through fourth quarter 1998. We thus had T = 116 observations on private consumption expenditures C_t and disposable income Y_t[27].

As is known from the seminal paper by Granger and Newbold (1974), the results from a simple regression of two non-stationary times series must be cautiously interpreted because of the "spurious regression" problem. Although the commonly employed test statistics often indicate a statistically significant relation, these are known to be highly unreliable and in fact misleading, as Phillips (1986) showed. In the case of non-stationary variables, the OLS-estimates of the regression parameters do not have limiting normal distribution, but converge to some functional on Brownian motion. Therefore, these test statistics do not qualify for the asymptotic theory, that forms the rationale for the commonly employed specification tests in the classical linear regression model.

A meaningful relation between two non-stationary time series exists however, if both share a common trend. This is the case, if e. g. in a regression of C_t on Y_t both variables are integrated of order 1, while some linear combination $U_t = C_t - \alpha - \beta \cdot Y_t$ is stationary. In this case the variables are termed to be co-integrated of degree one [Engle and Granger (1987)]. Thus, the first step in our estimation strategy is to test each of the time series separately for the existence of one or more unit roots in the data generating process.

Unfortunately we cannot use the standard unit root test as developed by Dickey and Fuller (1979, 1981), because we have a structural break in both series due to the

[26] Income was originally expressed in 1998 prices. Therefore we used a consumer price index to deflate them to the price level of 1993.

[27] Both time series were deflated using a consumer price index. Data were taken from: Deutsche Bundesbank (eds.): Saisonbereinigte Wirtschaftszahlen (Statistisches Beiheft zum Monatsbericht), various isssues.

reunification of Germany in 1990. The occurrence of a structural break at $t = 85$ corresponding to the 1st quarter of 1991 is clearly visible from the time series plots [see Panel (a) in Figure 4]. Therefore we use a modified version of the unit roots test as suggested by Perron (1989). The results are presented in Table 8.

Table 8 Results of unit roots test

Variable	T	λ	k	$\hat{\rho}$	$\hat{\tau}$
C_t	115	0.72	0	-0.099	-2.164
Y_t	112	0.72	3	-0.059	-1.457
ΔC_t	112	0.72	2	-0.962	-12.255*
ΔY_t	112	0.72	2	-0.895	-10.134*

Notes:

For the Perron test we use the standardized regression coefficient $\tau = \rho/\sigma_\rho$ from the OLS regression

$$\Delta X_t = a_0 + a_1 \cdot t + a_2 \cdot DS_{91} + a_3 \cdot DI_{91} + \rho \cdot X_{t-1} + \sum_{j=1}^{k} b_j \cdot \Delta X_{t-j} + E_t$$

as the test statistic. The variables apearing in this equation have the following meaning: X_t is the time series under consideration (either consumption or income); t is a time trend; DS_{91} is a step dummy variable, that is equal to zero in all periods prior to reunification (until 1990, 4th quarter), and is equal to one ever after; DI_{91} is an impulse dummy variable, that is equal to one only in the period, in which the structural break occurs (1991, 1st quarter), and zero in all periods before and after that date; E_t is the regression residual. The distribution of the test statistic depends on the parameter λ, which is equal to the proportion of 'pre-breakpoint' observations to the total sample size. An estimated value of τ that implies rejection of the Null hypothesis of a unit root at the 1% level is indicated by an asterisk. Critical values for the test statistic τ are tabulated in Perron (1989). The selection of the lag truncation parameter k was guided by a procedure advocated in Perron and Vogelsang (1992): Starting from k = 0, we add lags of ΔX, so that the last included coefficient was significant at the 10 % level and the last included coefficient in higher order autoregressions is insignificant. Given the asymptotic normality of these coefficients, we choose k such that the (k+1)-th coefficient had an t-value smaller than 1.65 in absolute value.

While the Null hypothesis of non-stationarity for the levels of both time series cannot be rejected at conventional significance levels, the change appears to be stationary for both variables. Thus we conclude, that both series are integrated of order 1 with a single structural break occurring in the last quarter of 1990.

The estimation of the cointegrating vector $\underline{b} = [-\alpha, -\beta]'$ could in principle be conducted using the ordinary least squares estimator (OLS) of the coefficients of a static regression of C_t on Y_t. Although this estimator can be shown to be *super-consistent* in the sense, that the parameter estimates converge to their true values at a higher rate than in the stationary case as the sample size increases [Stock (1987)], the OLS estimator may exhibit a bias due to sample size, possible endogenity of regressors as well as the presence of autocorrelation and heteroscedastisity of the residual process U_t. In all of these cases, conventional test statistics associated with the resulting estimate of $\underline{b}$ will exhibit non-standard distributions.

Therefore we employed the *fully modified least squares estimator* (FM-LS) as introduced by Phillips and Hansen (1990) in order to estimate the parameters of the cointegrating relationship[28]. This estimator is based on a semi-parametric correction method in order to obtain asymptotically efficient parameter estimates in the presence of endogenity and/or serial correlation of the residual process, and the t-statistics for the parameter estimates will have the usual limiting standard normal distribution.[29] The resulting parameter estimates are given by (t-values in parenthesis):

$$C_t = \underset{(-6.745)}{-19.605} + \underset{(134.152)}{0.917} \cdot Y_t,$$

$R^2 = 0.998$ Adj. $R^2 = 0.998$ DW = 0.761 F = 63921.2 $\sigma_{\hat{U}} = 7.417$.

Plots of the estimated consumption function, predicted values of consumption and the residuals are given in Panel (b) through (d) of Figure 4. In order to control for a possible influence of the structural break in both of the marginal processes on the parameters of the cointegrating relationship, we employ a test for parameter instability. The suggested test is a modified version of the standard F-test for parameter equality in two arbitrarily chosen subsamples. It is a test of the Null-hypothesis H_0: $\underline{b}_t = \underline{b}$, for all t (parameter constancy) against the alternative H_A: $\underline{b}_t = \underline{b}_1$ for $t \leq t_{br}$ and $\underline{b}_t = \underline{b}_2$ for $t > t_{br}$ (a single structural break occurs at some unknown date $t_{br} \in T$). The SupF-test statistic is obtained by choosing the maximum value of the modified F-test statistic for all possible dates in some pre-specified range $[t_{min}, t_{max}]$, which may be expressed as a fraction of the total sample size T. Following Hansen (1992), we used the range $[0.15 \cdot T, 0.85 \cdot T]$ and obtained a value of the SupF test-statistic equal to 7.19, which is well below the corresponding critical value of 13.4 at the 10% significance level[30]. Thus, we conclude that the parameter estimates appear to be stable, despite the apparent structural shifts in both of the marginal processes in the 4th quarter of 1991.

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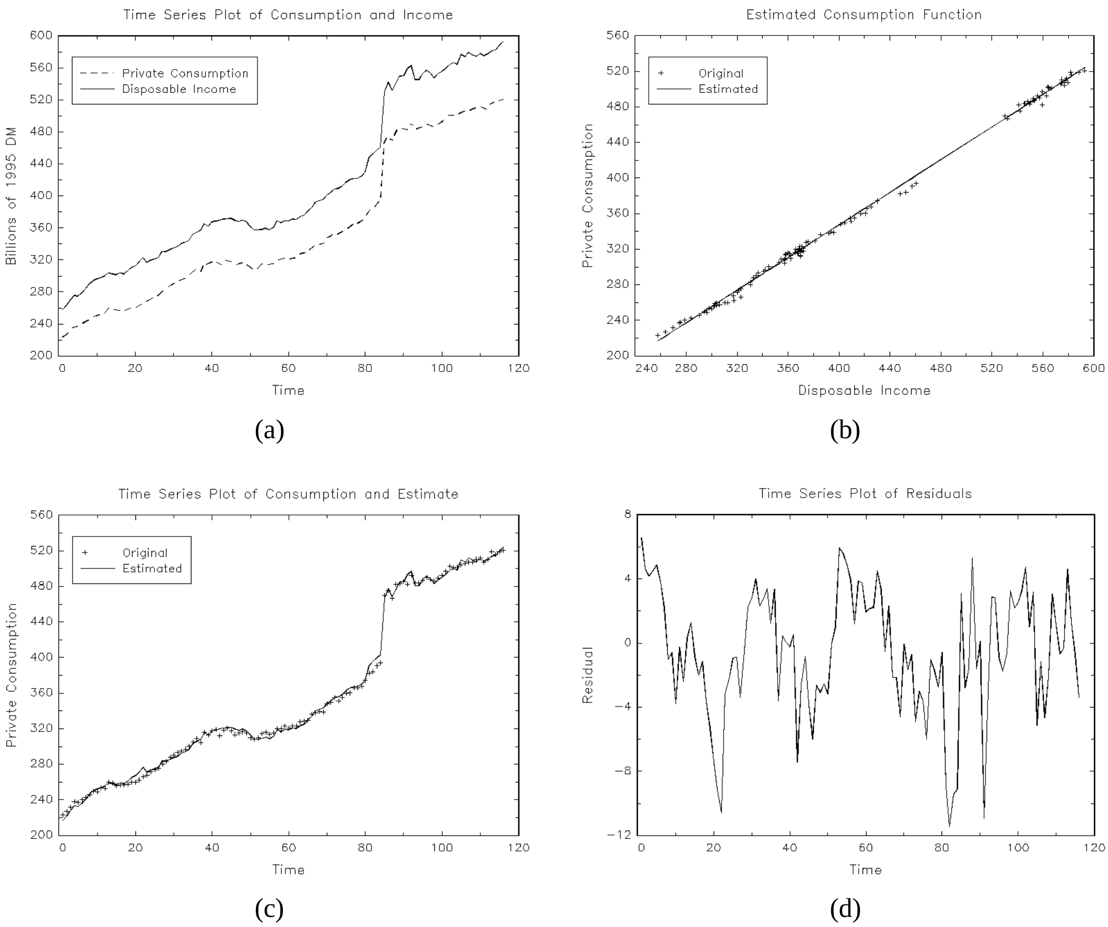
28 See Hamilton (1994) for a discussion of alternative estimation strategies for cointegrating relations.

29 Estimates of the long-run covariance matrix of the residual process were obtained based on a prewhitened estimate of the spectral density matrix at frequency zero using the quartic spectral kernel and an automatic bandwidth selection procedure as recommended by Andrews (1991). See Phillips and Hansen (1990) on details of the estimation procedure.

30 Further details on the computation of the test-statistic as well as critical values for the SupF-test are given in Hansen (1992).

Figure 4 The consumption function



A unit roots test of the residual process from this equation $\hat{U}_t$ can be conducted using the OLS parameter estimates from the following specification

$$\Delta\hat{U}_t = \rho \cdot \hat{U}_{t-1} + \sum_{i=1}^{k} a_i \cdot \Delta\hat{U}_{t-i} + E_t ,$$

where we chose the maximum lag length k, so that the last included coefficient was significant at the 10 % level, while higher order terms were not. Critical values for the distribution of the standardized regression coefficient $\hat{\tau} = \hat{\rho}/\sigma_{\hat{\rho}}$ can be found in MacKinnon (1991). For k = 1 and T = 114 the estimate of ρ was equal to -0,34 and the corresponding value of $\hat{\tau}$ was equal to -4.114, while the corresponding critical value at the 1%-significance level is equal to –3.99. Thus our findings suggest, that the Null hypothesis of non-stationarity of $\hat{U}_t$, which would imply non-cointegration between Y_t and C_t, may be rejected.

The last step of our cointegration analysis involves the estimation of the corresponding error correction model, which consists of the following dynamic system of equations for ΔC_t and ΔY_t:

$$\Delta C_t = \underset{(5.53)}{2.09} - \underset{(-0.64)}{0.07} \cdot \hat{U}_{t-1} - \underset{(-2.43)}{0.28} \cdot \Delta C_{t-1} - \underset{(-2.90)}{0.13} \cdot \Delta C_{t-2} + \underset{(2.43)}{0.28} \cdot \Delta Y_{t-1} + \underset{(19.93)}{74.16} \cdot DI_{91},$$

and

$$\Delta Y_t = \underset{(5.58)}{2.47} + \underset{(2.18)}{0.26} \cdot \hat{U}_{t-1} - \underset{(-0.87)}{0.11} \cdot \Delta C_{t-1} - \underset{(-2.70)}{0.14} \cdot \Delta C_{t-2} + \underset{(1.56)}{0.21} \cdot \Delta Y_{t-1} + \underset{(16.16)}{70.03} \cdot DI_{91}.$$

Both equations exhibit reasonable values sign for the parameter estimates of the error correction term $\hat{U}_{t-1}$, although the estimated value in the first equation is not significantly different from zero.[31] It seems as though the mechanism, that keeps both variables in a long-run equilibrium relation is driven primarily by the error correction model associated with the income variable Y_t.

In order to get a reasonable figure for the marginal propensity to consume that conforms to the definition of the income aggregate in the input-output table as well as to our survey data, we have to transform the estimated parameter from the specification above. The main difference between the input-output and the national accounts definition of income is that the latter is (a) net of taxes and (b) has the balance of transfer payments from the state to private households added. Therefore we multiply the propensity of consumption with an appropriate net ratio for each of the types of income, that we use in the assessment of induced effects. When computing the initial effects for the *induced impact from direct income* we multiply the original estimate of 0.917 by the ratio of disposable income *excluding* the balance of transfer payments *and* profits to the total gross wage and salary income. This ratio is equal to 0.51[32], so the resulting estimate for c_m is equal to 0.4677.

For all other calculations involving the assessment of induced effects[33], we retained the distributed profit incomes in the definition of the numerator of the net ratio. Thus we obtain a net ratio of 0.66[34] yielding a propensity to consume equal to 0.6052.

---

[31] Since all variables that appear in these equations are stationary, the t-statistics of the parameter estimates do have an asymptotical standard normal distribution.

[32] The total disposable income figure for the year 1997 was equal to 2 339 billion DM. The proportion of net wages and salaries to total disposable income was equal to 41.9 % or about 980 billion DM. This in turn corresponds to 51 % of the gross wage and salary incomes, which amount to 1 906 billion DM. Source: BMA (1998).

[33] This includes multiplier effects from the initial stimulus for the *induced impact from direct incomes*.

4.3. Results of the interregional and national input-output analysis

The estimation of indirect and induced effects of the Frankfurt Airport is structured in two parts. First we estimate impacts on the overall economy using the ordinary version of the extended input-output model as discussed in section 2.2. These figures are contrasted to the regional impact for which we employed the interregional extended input-output model that we developed in section 2.3.

From Table 9 we can see, that the employment in the sector "Transportation, communications" exhibits the strongest indirect dependence on the economic activities at the airport, followed by "Other market services" and "New construction and maintenance". These results, in a sense, mirror the distribution of the initial effects, where these three sectors also had the highest shares. The induced effects follow a slightly different pattern. Here the "Trade" sector has the pole position with respect to airport-depended employment, followed by "Transportation…" and "Other market services". All in all, one can deduce, that sectors belonging to the service industry dominated in benefits from the airport-based activities relative to the primary and secondary sectors of the overall economy.

The distribution of sectoral income effects follows the overall pattern observed for the employment effects, with one notable exception. Neither the national nor the regional input-output tables report employment figures for the sector "Real estates and rentals", so labor coefficients and accordingly all employment effects are equal to zero, while income figures are reported in both tables. As can be seen in Table 9, a high share of total induced income is being generated in this sector.

[34] The distributed profits amount to 830 billion DM or about 30 % of the total disposable income. Source: BMA (1998).

Table 9 Employment and income effects on the overall economy

Sector	Employment			Income		
	Indirect	Induced	Total	Indirect	Induced	Total
Agriculture and fisheries	1.48	3.24	4.72	27	59	87
Coal, gas, electric power, ...	3.64	3.26	6.90	374	336	710
Primary metals	0.90	0.39	1.30	52	22	74
Mechanical engineering, data processing ...	4.74	1.37	6.10	332	96	428
Motor vehicles	4.04	1.75	5.79	210	91	301
Fabricated metal products, ...	0.37	0.54	0.91	26	37	63
Lumber and wood products, ...	2.59	2.83	5.42	147	161	308
Food and kindered products, tobacco	1.77	2.97	4.74	146	246	393
New construction and maintenance	5.39	1.43	6.82	357	95	453
Trade	2.85	13.07	15.92	159	731	891
Transportation, communications	15.94	4.34	20.27	918	250	1 168
Banking, finance, insurance	0.91	3.20	4.11	19	67	86
Real estate and rentals	0.00	0.00	0.00	157	772	929
Catering trade	1.27	3.38	4.65	43	115	159
Culture, health	0.54	2.63	3.17	36	172	208
Other market services	8.08	5.99	14.06	848	629	1 477
Governmental units, ...	0.70	4.12	4.82	40	236	276
Total	55.19	54.51	109.70	3 892	4 115	8 007

Employment: Thousand persons. Income: Millions of DM in 1993 prices.

The national employment multiplier as defined in section 2.4 is given by

$$m^{E} = \frac{(55.19 + 54.51)}{62.05} = 1.77,$$

so, for each job on the airport site another 1.77 jobs nationwide depend on the airport activities. The corresponding income multiplier is given by

$$m^{W} = \frac{(3\,892 + 4\,115)}{3\,982} = 2.01.$$

From this figure we can see that for each DM of gross income received by the airport employees an additional amount of DM 2.01 is being earned in the overall economy.

Turning to the results from the interregional input-output model, we note that the sectoral distribution of economic effects closely resembles the patterns observed in the national model. An interesting feature of the interregional framework is the possibility to decompose total economic impact for both regions, Hessen and Rest of Germany. As can be seen from Table 10, the bulk of the induced effects in terms of employment as well as in terms of income arise in Rest of Germany, while the reverse is true with respect to the indirect effects. This effect is due to the higher proportion of total consumption expenditures that stem from domestic production in the Rest of Germany, where we observe a consumption structure coefficient c_R equal to 0.82. The corresponding sum of the consumption structure coefficients for the domestic production in Hessen $\Sigma\, c_{H,i}$ amounts to 0.59. Also, the proportion of consumption expenditures in the Rest of Germany that is produced in Hessen $\Sigma\, c_{H\rightarrow R,i}$ makes up only about 1.3% of the total consumption expenditures in the Rest of Germany, whereas 22.5% of the Hessian consumption comes from the Rest of Germany. Thus, the trading balance in terms of consumption goods strongly favors the Rest of Germany.

Since we are only interested in economic effects that prevail in the regional economy of Hessen, we neglect the output generated in the Rest of Germany when we compute the employment and the income multipliers, so the regional employment multiplier for Hessen amounts to

$$m^E = \frac{(46.30 + 17.25)}{53.44} = 1.19,$$

and the corresponding income multiplier is given by

$$m^W = \frac{(2\,265 + 1\,545)}{3\,430} = 1.11.$$

Table 10 Employment and income effects for the region of Hessen

Sector	Employment			Income		
	Indirect	Induced	Total	Indirect	Induced	Total
Agriculture and fisheries	0.45	0	0.92	8	8	16
Coal, gas, electric power, ...	1.09	0	1.58	107	49	156
Primary metals	0.14	0	0.16	7	1	9
Mechanical engineering, data processing ...	2.43	0	2.59	172	12	184
Motor vehicles	1.15	0	1.42	59	14	73
Fabricated metal products, ...	0.09	0	0.15	6	4	9
Lumber and wood products, ...	0.70	0	1.06	38	20	57
Food and kindered products, tobacco	1.32	1	1.98	94	48	142
New construction and maintenance	4.05	0	4.44	291	28	320
Trade	0.61	5	5.93	34	296	330
Transportation, communications	30.98	2	33.18	894	63	957
Banking, finance, insurance	0.24	1	1.11	23	84	107
Real estate and rentals	0.00	0	0.00	62	346	408
Catering trade	0.38	2	2.06	12	54	66
Culture, health	0.21	1	1.33	15	77	92
Other market services	2.36	2	4.37	435	371	806
Governmental units, ...	0.12	1	1.27	7	70	77
Sum	46.30	17.25	63.55	2 265	1 545	3 809
Rest of Germany	7.51	22	29.42	523	1 527	2 051
Total	53.81	39	92.97	2 788	3 072	5 860

Employment: Thousand persons. Income: Millions of DM in 1993 prices.

Both regional multipliers are lower than the corresponding figures for the overall economy. This results nicely conforms to results from previous studies of multiplier effects, that were conducted for a number of airports in Germany. A summary of their main results is given in Table 11.

Table 11 Results of previous economic impact studies for airports in Germany

Authors	Airport	Year	Income multiplier		Employment multiplier	
			national	regional	national	regional
Hübl et al. (1994)	Hannover	1993	2.10	1.60	1.95	1.46
Aring et al. (1996)	Hamburg	1994	1.65	-	1.70	1.30
Baum et al. (1998)	Köln/Bonn	1996	2.65	2.00	3.04	2.31
Bulwien & Partner (1998a)	München	1996			2.01	1.62
Bulwien & Partner (1998b)	Nürnberg	1996	-	-	1.96	1.46

While the order of magnitude of our employment and income multipliers for the overall economy is about the same as reported in most of the other studies, we find lower multipliers on the regional level. This outcome can only in part be attributed to the use of our new interregional input-output model. Because original input-output tables on the state level are not regularly provided by statistical offices for most of the German federal states ("Bundesländer"), the usual practice is to use the national input-output table in combination with regional initial effects. As demonstrated in section 3.1, this procedure results in overestimation of the true regional effects, because of the lower sectoral input coefficients and output multipliers typically observed in regional input-output tables.

5. Summary and conclusions

We developed an interregional version of the standard textbook input-output model, that is extended with respect to the inclusion of the consumption expenditures and income generation process into the endogenous part of the input-output table. We also demonstrated a new method for deriving a two-region version of an interregional input-output table from original input-output tables for an overall economy and one of its regions. In an empirical assessment of the economic effects of the Frankfurt Airport, the interregional model was successfully employed. It was shown, that the model is capable of reducing the degree of overestimation of economic effects that results from inappropriate use of national input-output tables in the assessment of regional impact effects.

Appendix

A1. Conditions for the non-negativity of extended multipliers

In order to show the non-negativity of multipliers in the model of Pischner and Stäglin, we transform the matrix of sectoral production multipliers $(\underline{I}-\underline{A})^{-1}\cdot(\underline{I}-\underline{V})^{-1}$ as follows

$$
\begin{aligned}
(\underline{I}-\underline{A})^{-1}\cdot(\underline{I}-\underline{V})^{-1} &= \left[(\underline{I}-\underline{A})-\underline{V}\cdot(\underline{I}-\underline{A})\right]^{-1} \\
&= \left[(\underline{I}-\underline{A})-\underline{c}_s\cdot c_m\cdot\underline{b}'\cdot(\underline{I}-\underline{A})^{-1}\cdot(\underline{I}-\underline{A})\right]^{-1} \\
&= \left[\underline{I}-(\underline{A}+\underline{c}_s\cdot c_m\cdot\underline{b}')\right]^{-1} \\
&= \left[\underline{I}-\underline{Z}\right]^{-1}.
\end{aligned}
$$

The elements of $\underline{Z}\equiv\underline{A}+\underline{c}_s\cdot c_m\cdot\underline{b}'$ can be written as

$$
\underline{Z}=\begin{pmatrix} a_{11}+b_1\cdot c_1\cdot c_m & \cdots & a_{1n}+b_n\cdot c_1\cdot c_m \\ \vdots & \ddots & \vdots \\ a_{n1}+b_1\cdot c_n\cdot c_m & \cdots & a_{nn}+b_n\cdot c_n\cdot c_m \end{pmatrix}.
$$

In order to establish non-negativity of $(\underline{I}-\underline{Z})^{-1}$, we will employ the Brauer-Solow criterion[35], which gives a sufficient condition. It states that all elements of $(\underline{I}-\underline{Z})^{-1}$ will be non-negative, if the matrix $\underline{Z}$ is such, that

(a) $\underline{Z}$ is indecomposable[36]

(b) $z_{ij}\geq 0$,

(c) $\sum_{i=1}^{n} z_{ij}\leq 1$ for all i, j = 1, …, n and

(d) $\sum_{i=1}^{n} z_{ij}<1$ for at least one j = 1,…,n.

Applying the Brauer-Solow criterion thus requires the assumption, that there is at least one industry, that uses additional inputs besides the intermediate inputs and labor in production, so for this industry the sum of all intermediate input coefficients plus the income coefficient is strictly less than one. Additionally, indecomposability of $\underline{Z}$ has to be imposed. In practice one will rarely find an input-output table that does not satisfy these requirements.

Solving for the column sum of the j-th industry we find

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[35] See Solow (1952), Theorem 1.

[36] If a square matrix can be partitioned in a block triangular form simply by rearranging rows and columns it is *decomposable*, otherwise it is *indecomposable*.

$$\sum_{i=1}^{n} a_{ij} + b_j \cdot c_m \cdot \sum_{i=1}^{n} c_i \,.$$

With respect to the marginal propensity to consume we expect to have values in the range $0 \le c_m \le 1$. Also, the sum of the sectoral consumption coefficients is at most equal to one, so the product of this sum with c_m is also at most equal to one. From this we can immediately see, that the sum will never exceed one, since

$$0 \le \sum_{i=1}^{n} a_{ij} + b_j \le 1 \,,$$

and as long as there are primary inputs other than labor for at least one sector, the corresponding second inequality is strict and the Brauer-Solow criterion applies. In order to prove non-negativity of the gross output for the interregional model of section 2.2., we again transform the matrix of sectoral production multipliers

$$\begin{aligned}
(\underline{I} - \underline{A}^*)^{-1} \cdot (\underline{I} - \underline{V}^*)^{-1} &= \left[(\underline{I} - \underline{A}^*) - \underline{V}^* \cdot (\underline{I} - \underline{A}^*)\right]^{-1} \\
&= \left[(\underline{I} - \underline{A}^*) - \underline{C}_s^* \cdot c_m \cdot \underline{T} \cdot \underline{B}^* \cdot (\underline{I} - \underline{A}^*)^{-1} \cdot (\underline{I} - \underline{A}^*)\right]^{-1} \\
&= \left[\underline{I} - (\underline{A}^* + \underline{C}_s^* \cdot c_m \cdot \underline{T} \cdot \underline{B}^*)\right]^{-1} \\
&= \left[\underline{I} - \underline{Z}^*\right]^{-1}.
\end{aligned}$$

The elements of $\underline{Z}^* \equiv \underline{A}^* + \underline{C}_s^* \cdot c_m \cdot \underline{T} \cdot \underline{B}^*$ are equal to

$$\underline{Z}^* = \left(\begin{array}{ccc|c}
a_{11} + b_1 \cdot c_1 \cdot c_m & \cdots & a_{1n} + b_n \cdot c_1 \cdot c_m & a_{1R} + b_R \cdot c_{H\to R,1} \cdot c_m \\
\vdots & \ddots & \vdots & \vdots \\
a_{n1} + b_1 \cdot c_n \cdot c_m & \cdots & a_{nn} + b_n \cdot c_n \cdot c_m & a_{nR} + b_R \cdot c_{H\to R,n} \cdot c_m \\
\hline
a_{R1} + b_1 \cdot \sum_{i=1}^{n} c_{R\to H,i} \cdot c_m & \cdots & a_{Rn} + b_n \cdot \sum_{i=1}^{n} c_{R\to H,i} \cdot c_m & a_{RR} + b_R \cdot c_R \cdot c_m
\end{array} \right),$$

so the sum of any of the first n columns can be written as

$$a_{Rj} + \sum_{i=1}^{n} a_{ij} + b_j \cdot c_m \cdot \left(\sum_{i=1}^{n} c_i + \sum_{i=1}^{n} c_{R\to H,i} \right),$$

while the last column sum is equal to

$$a_{RR} + \sum_{i=1}^{n} a_{iR} + b_R \cdot c_m \cdot \left(c_R + \sum_{i=1}^{n} c_{H\to R,i} \right).$$

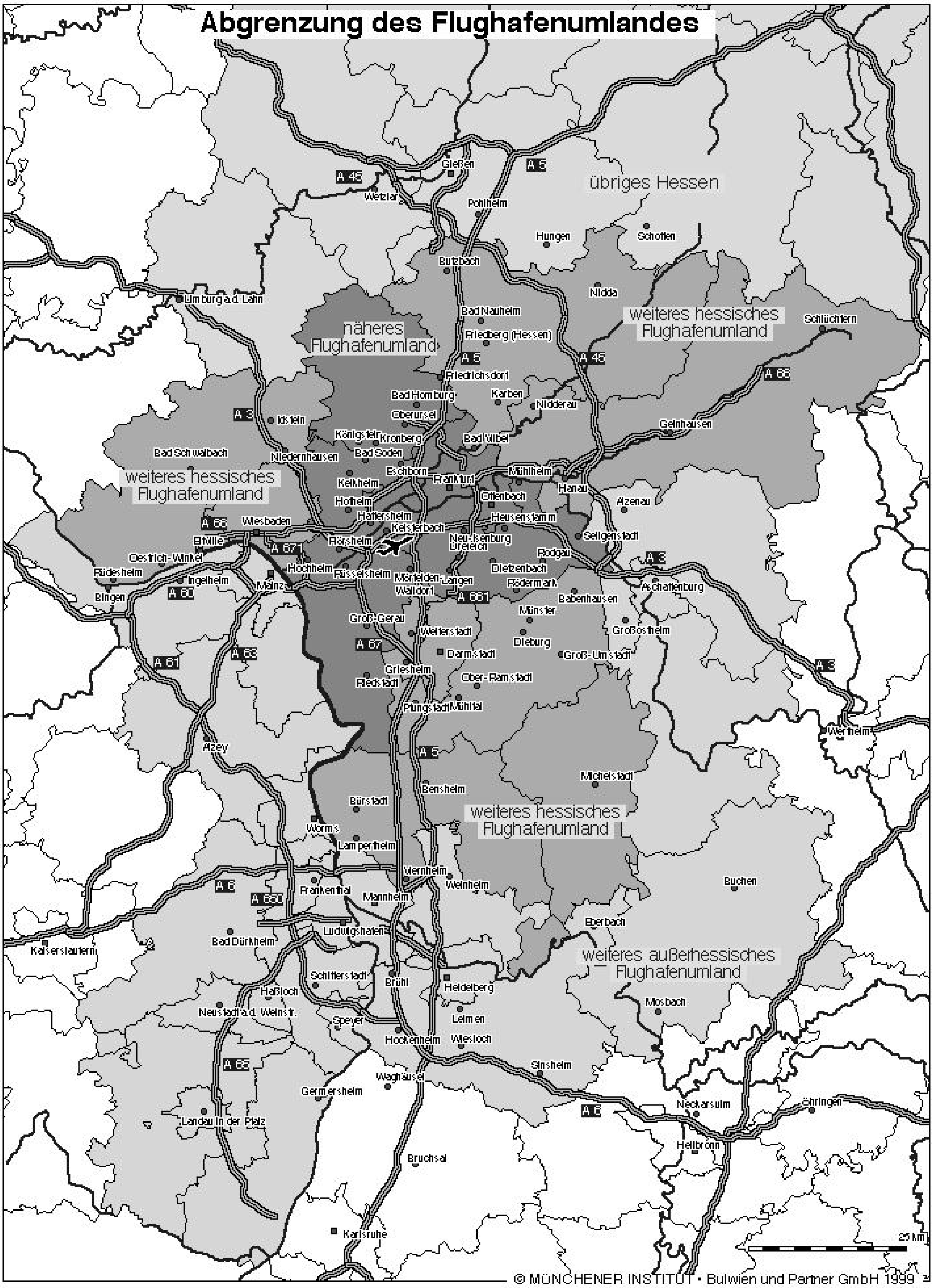
Noting that the sum of the consumption coefficients for any of the two regions will again be at most equal to one, we can immediately deduce, that under the same assumptions as in the case of the ordinary extended model, the inverse of ($\underline{I}$ - $\underline{Z}^*$) will have only non-negative elements.

A2. Regional subdivisions

Table A1 Definition of regional subdivisions

No.	Regional subdivision	Definition
1	Frankfurt airport (FRA)	On the airport site, area is part of the municipal area of Frankfurt
2	Municipal area Frankfurt, surrounding countryside in Hessen close to airport	Frankfurt without airport site, town of Offenbach, county Offenbach, Main Taunus county, Hochtaunus county, county of Groß-Gerau
3	Distant surrounding countryside in Hessen	Town of Wiesbaden / Rheingau-Taunus-county, Wetterau-county / Main-Kinzig- county, remaining parts of Darmstadt county
4	Rest of Hessen	County Limburg Weilburg, county Fulda, remaining part of Giessen county, remaining part of Kassel county
5	Distant surrounding countryside outside of Hessen	Town of Aschaffenburg, county of Aschaffenburg, county of Miltenberg, town of Frankenthal, town of Landau in der Pfalz, town of Ludwigshafen am Rhein, town of Neustadt an der Weinstraße, town of Speyer, county of Bad Dürkheim, county of Germersheim, county of Südliche Weinstraße, county of Ludwigshafen, town of Mainz, town of Worms, town of Alzey-Worms, county of Mainz-Bingen, town of Heidelberg, town of Mannheim, Neckar-Odenwald-county, Rhein-Neckar-county
6	Rest of Germany	Federal Republic of Germany excluding subdivisions 1 to 5
7	Foreign countries	Rest of the world

Figure A1 Map of the surrounding area of the Rhine-Main airport Frankfurt



Source: Bulwien and Voßkamp (1999)

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