doi:10.1111/j.1435-5957.2009.00268.x

Spatial aspects of trade liberalization in Colombia: A general equilibrium approach*

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Received: 28 April 2008 / Accepted: 8 September 2008

Abstract. This paper offers some preliminary steps in the marriage of some of the theoretical foundations of new economic geography with spatial computable general equilibrium models. Modelling the spatial economy of Colombia using the traditional assumptions of computable general equilibrium (CGE) models makes little sense when one territorial unit, Bogotá, accounts for over one quarter of GDP and where transportation costs are high and accessibility low compared to European or North American standards. Hence, handling market imperfections becomes imperative as does the need to address internal spatial issues from the perspective of Colombia's increasing involvement with external markets. The paper builds on the Centro de Estudios de Economia Regional (CEER) model, a spatial CGE model of the Colombian economy; non-constant returns and non-iceberg transportation costs are introduced and some simulation exercises carried out. The results confirm the asymmetric impacts that trade liberalization has on a spatial economy in which one region, Bogotá, is able to more fully exploit scale economies *vis-à-vis* the rest of Colombia. The analysis also reveals the importance of different hypotheses on factor mobility and the role of price effects to better understand the consequences of trade opening in a developing economy.

JEL classification: R13, F17, D58

Key words: Trade liberalization, spatial general equilibrium, CGE, Latin America, New Economic Geography

* We are grateful for very helpful comments on an earlier draft from two anonymous referees.

1 Introduction

Colombia was late in its efforts towards the integration of the country in the global network,[1] as was the case of most Latin American countries until the 1990s. Among the measures adopted in the trade reforms, initiated in the late 1980s, the restructuring of the tariff schedule played an important role. Even though some tariffs were reduced drastically, it has been argued that there are still areas where further structural reforms are needed in Latin America, including scaling back remaining high tariffs.[2] However, the modelling of changes of trade policy in Colombia has always neglected the regional dimension. To our knowledge, this is the first attempt to look at the spatial consequences of trade liberalization in Colombia, from a general equilibrium perspective.[3] At the national level, there have been several attempts to evaluate the impact of trade liberalization on the economy. This literature has been stimulated by the free trade agreement (FTA) that Colombia has been negotiating with the United States since 2004. According to Toro et al. (2006), these studies concluded that there will be an increase in the trade deficit after the FTA's application, while the economy growth rates, depending on the model used, range between 1% and 4%, but the fiscal cost would not be very large.[4]

Other authors are less optimistic about the impact of trade liberalization on the economic performance. For instance, Ocampo et al. (2004) estimated the short-run (fixed capital stocks) effects of a uniform 50% decrease in tariff rates showed a positive performance of the economy: real GDP increased by 0.27%.[5]

However, with the exception of Ocampo et al. (2004), who explored the effects of protectionism on the distribution of income between urban and rural households, no attention has been directed to differential regional impacts. Since Colombia exhibits huge differences in the development of its regions, it is important to evaluate the spatial impacts of trade policies. We explore in this paper a cost-competitiveness approach, based on relative changes in the sectoral and regional cost and demand structures, to isolate the likely spatial effects of further tariff reductions in Colombia.

We found considerable differences in the short-run and long-run impacts. While, in the short-run, structural constraints impose a spatial trap that leads to more concentration, in the long-run factor, mobility enables spatial re-location of production in a way that regional disparities tend to diminish. Long-run results using the spatial computable general equilibrium (CGE) approach can reconcile theoretical predictions based on recent economic geography models with empirical applications to real economies. In summary, such results show that the openness of the Colombian economy leads to a reduction of Bogotá's primacy and greater regional specialization, as suggested by Krugman and Elisondo (1996).

The paper is organized as follows: Section 2 provides a description of the regional setting in Colombia, highlighting spatial inequality in the country. Following Section 3 discusses some of the theoretical and empirical literature that attempts to address spatial aspects of trade liberalization. Section 4 presents the model used in the trade policy simulations. Section 5 presents and discusses the short-run and long-run impacts of the tariff reduction experiment. Final remarks conclude the paper, discussing limitations of the model and analysis.

[1] Starting in 1985, Colombia experienced gradual trade liberalization that culminated in the drastic tariff reductions of 1990–1991. Average tariff declined 27% to about 10% from 1984 to 1998. (Attanasio et al. 2004).

[2] World Economic Outlook, April 2003.

[3] One pioneer work using a multiregional CGE model for Colombia is Iregui (2005). This paper quantifies the welfare effects of decentralization considering five geographic regions.

[4] Some of the papers focus on the analysis of the impacts of the FTA with the United States using CGE models are DNP (2003), Botero (2004), and Martín and Ramírez (2005). Other authors studying the effects of trade liberalization on the Colombian economy with the same methodological approach are Light and Rutherford (2003), Esguerra et al. (2004), and Vaughan (2005).

[5] The CGE model was calibrated for 1997.

2 The regional setting

The spatial distribution of economic activity in Colombia can be gauged through the analysis of the evolution of the gross departmental income.[6] According to Bonet and Meisel (2006), the main feature is the dominance of Bogotá. The national capital showed a growing share in the national gross income, from 30% in 1975 to 36% in 2000. Additionally, Bogotá's per capita gross income was, on average, more than double the national mean. Bogotá's supremacy became more evident during the 1990s, when there was a bi-modal distribution with Bogotá located in the upper side and the rest of the country in the lower. What can be observed is that some departments that used to be above the national average such as Antioquia, Atlántico and Valle, moved closer to the mean during the 1990s. As a result, these departments converge to those territorial entities that were below the national average. Finally, another element is the persistence in the disparities during all the 25 years studied; Bogotá is always top of the per capita gross income ranking, while the departments located in the periphery occupying the last positions (Caquetá, Cauca, Cesar, Córdoba, Chocó, Nariño, Norte de Santander, Magdalena and Sucre).

In accordance with their share in gross national income, the territorial entities may be grouped into four categories. In the first stands Bogotá, this generated more than a third of the total gross income. The second group is made up of Antioquia and Valle, which registered shares that oscillate between 10 and 15%, with a descending tendency during the period. The third group is composed of departments which maintained their shares at a level close to 5%: Atlántico, Cundinamarca and Santander. The rest of the departments registered shares at rates of less than 3%, with a number of extreme cases like Caquetá, Chocó, La Guajira and Sucre, which registered rates of less than 1%. With the exception of Bogotá and the new departments (located mainly in the Amazon region), the territorial entities showed decreasing or relatively stable trends. Bogotá of course accounted for the largest share (see Figure 1).

To provide an idea about the strength of the linkages in the Colombian economy, from a spatial perspective, Figure 2 shows the average distribution of the impacts associated with the input-output table embedded in the Centro de Estudios de Economia Regional (CEER) model. The spatial concentration is again perceived as the extended core region of the country. Its ability to internalize multiplier effects from the whole economy represents a further evidence of spatial concentration in Colombia. Given the nature of the (backward) linkages associated with the Colombian economic structure, there appear elements for a 'spatial trap' for the country, as all the regions are somehow dependent on the core.

3 Spatial aspects of trade liberalization

The effects of trade reforms have been extensively studied in the international trade literature. However, as noticed by Goldberg and Pavcnik (2004), the literature on the relationship between trade and growth is already vast, and has failed to reach a consensus on the effect of trade on growth. Trade liberalization processes are said to have benefits derived from gains in both the production side (there is an overall increase in the foreign exchange revenue earned in export industries, or saved in import industries, per unit of labour and capital) and the consumption side (the same basket of products can be obtained at lower cost). However, the liberalization process also involves two kinds of short-run costs to the economy: distributional costs (protected sectors tend to lose) and balance of payments pressures due to the rapid increase in imports (Bruno

[6] Colombia is politically divided into nation, departments, districts, and municipalities. Nation is formed by departments which are formed by municipalities. There are also districts which are municipalities with higher territorial status.

Fig. 1. Departmental share of gross national income, 2000
Source: Bonet and Meisel (2006).

1987). However, the short-term growth consequences of a trade reform will depend on the structure of the reforming economy. From a spatial perspective, the short-run effects will also be heavily influenced by the respective regional structures. The first set of simulations in this paper will try to address some of these issues.

The second set of simulations is inspired by the work by Krugman and Elisondo (1996). They have shown that trade policies of developing countries and their tendency to develop huge metropolitan centres are closely linked. They developed a spatial model in the new economic geography (NEG) tradition, whose equilibrating mechanisms draw heavily on the balance of real wage differentials through labour mobility. Their Krugman-type core-periphery model, inspired by the case of Mexico, explained the existence of such giant cities as a consequence of the strong forward and backward linkages that arise when manufacturing tries to serve a small domestic market. The model implies that these linkages are much weaker when the economy is open to international trade; in other words, closed markets promote huge central agglomerations, while open markets discourage them.

As seen in Section 2, Colombia is characterized by strong spatial concentration. Bogotá, the capital city, is responsible for around 25% of total GDP (28% in manufacturing), and covers only 0.14% of total territory. Trade opening should then reduce its relative importance. From the work by Krugman (1994), Krugman and Elisondo (1996), Puga (1998), and Alonso-Villar

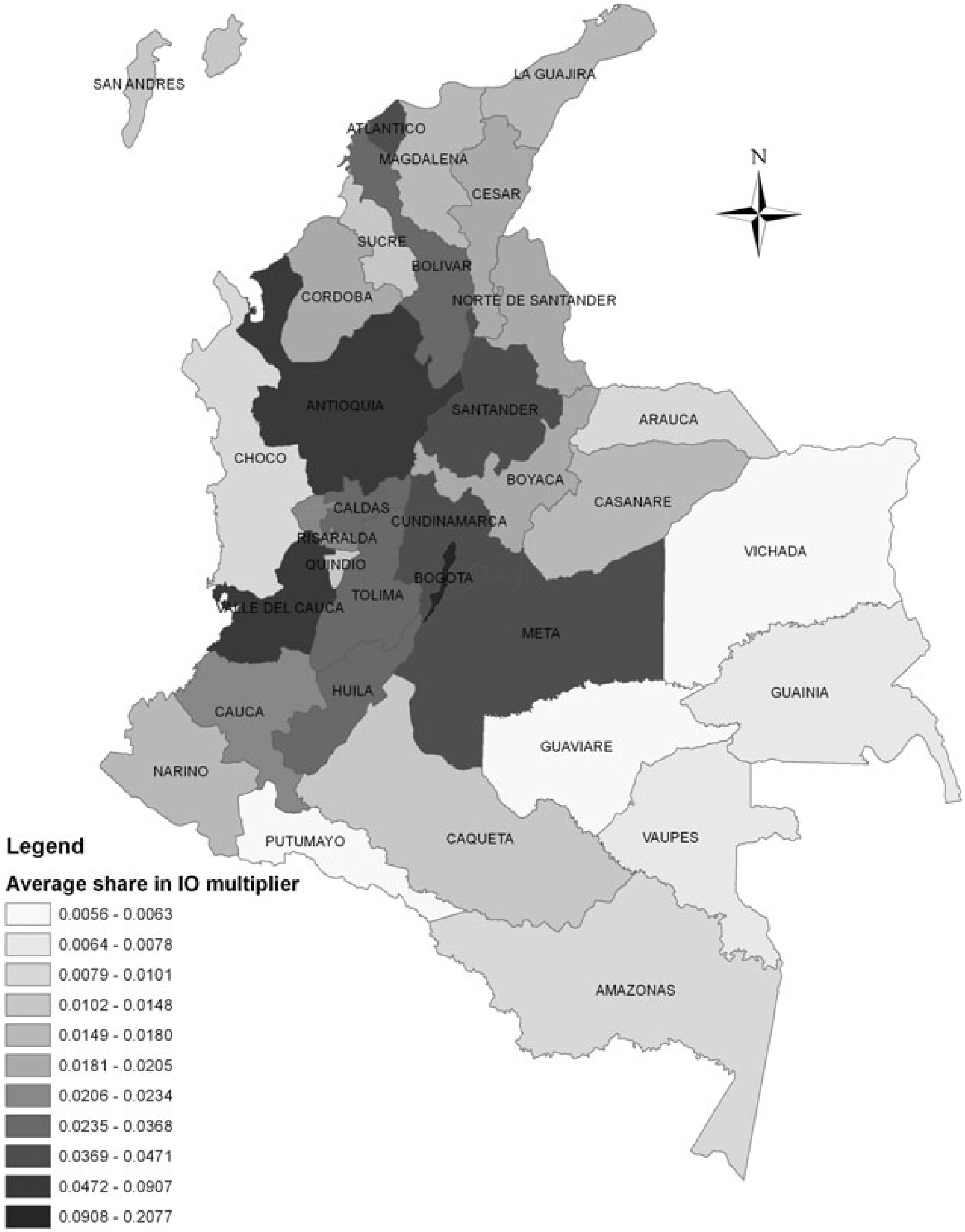

Fig. 2. Linkages in Colombia (average % share in net I-O output multipliers)

(2001), the notion is advanced that trade liberalization policies may reduce regional inequality in developing countries, especially by reducing the size of primate cities or at least reducing their relative growth. Trade liberalization would also lead to more specialized regions. Given the long-run nature of these models, a final result would be strongly related to population movements from the core region, which would ultimately increase welfare through reduction of congestion costs. However, empirical studies are not conclusive about these results.

Ades and Glaeser (1995), using cross country data, corroborated Krugman and Elisondo's predictions, showing that countries with high shares of trade in GDP or low tariff barriers (even holding trade levels constant) rarely have their population concentrated in a single city. The case of Mexico seems to reinforce the theoretical results. Hanson (1998) showed that trade reform appears to have contributed to the breakup of the Mexico City manufacturing belt and the formation of new industrial centres in northern Mexico. However, the reality of Brazil, another major Latin American country, seems to be more complex, as trade liberalization in the 1990s did not produce any relevant de-concentration from the core region (Haddad 1999; Haddad and Azzoni 2001). As Haddad and Hewings (2005) point out, one should consider some intermediate perspectives between a core-periphery model, on the one hand, and a perfectly competitive, homogeneous space model at the other extreme. In the Brazilian case, firms can exploit increasing returns to scale without serving a national market; in large part, market imperfections derive from transportation costs that essentially serve to segment markets. Further, the asymmetries in the distribution of productive activity, with the primacy of São Paulo, serve to strengthen existing competitive advantages. In a context of trade opening, peripheral regions may have then been adversely affected.

One of the first attempts to test the Krugman and Elisondo model in Colombia was made by Fernández (1998). This author concludes that, contrary to the predictions of the theory, the empirical evidence suggests a positive relationship between agglomeration and trade for most sectors, excluding food, beverages and chemicals, which showed a negative association. As Fernández pointed out, further work should make a model more suitable for the Colombian case, and also that the effects of changes in trade liberalization in agglomeration may take longer to be seen. In the second set of simulations, this paper looks at the Colombian case, from a long-run perspective. In addition, the model presents a finer spatial disaggregation, considering all 32 departments plus Bogotá, rather than just two cities, Bogotá and Barranquilla, as in Fernández's approach. A rather more realistic approach to spatial phenomena is considered, as opposed to stylized models that have been used so far.

4 The CEER Model

In this paper, we present the CEER[7] model, the first fully operational spatial CGE model for Colombia.[8] The paper uses a similar approach to Haddad and Hewings (2005) to incorporate recent theoretical developments in the new economic geography. Experimentation with the introduction of scale economies, market imperfections, and transportation costs provide innovative ways of dealing explicitly with theoretical issues related to integrated regional systems. The model used in this research contains over 35,000 equations in its condensed form, and it is designed for policy analysis. Agents' behaviour is modelled at the regional level, accommodating variations in the structure of regional economies. Regarding the regional setting, the main innovation in the CEER model is the detailed treatment of interregional trade flows in the Colombian economy, in which the markets of regional flows are fully specified for each origin and destination. The model recognizes the economies of the 32 Colombian departments and the capital city, Bogotá.

Results are based on a bottom-up approach – namely, national results are obtained from the aggregation of regional results. The model identifies seven production/investment sectors in each region producing seven commodities (Table 1), one representative household in each region, regional governments and one Central government, and a single foreign area that trades

[7] Centro de Estudios de Economia Regional del Banco de la Republica, Colombia.
[8] Full model description is available in the appendix.

Table 1. Sectors in the CEER model

1	Agriculture
2	Mining
3	Manufacturing
4	Construction
5	Transportation
6	Public administration
7	Other services

with each domestic region. Two local primary factors are used in the production process, according to regional endowments (capital and labour).

The basic structure of the CGE core module comprises three main blocks of equations determining demand and supply relations, and market clearing conditions. In addition, various regional and national aggregates, such as aggregate employment, aggregate price level, and balance of trade, are defined. Nested production functions and household demand functions are employed; for production, firms are assumed to use fixed proportion combinations of intermediate inputs and primary factors in the first level while, in the second level, substitution is possible between domestically produced and imported intermediate inputs, on the one hand, and between capital and labour, on the other. At the third level, bundles of domestically produced inputs are formed as combinations of inputs from different regional sources. The modelling procedure adopted in CEER uses a constant elasticity of substitution (CES) specification in the lower levels to combine goods from different sources.

The treatment of the household demand structure is based on a nested CES/linear expenditure system (LES) preference function. Demand equations are derived from a utility maximization problem, whose solution follows hierarchical steps. The structure of household demand follows a nesting pattern that enables different elasticities of substitution to be used. At the bottom level, substitution occurs across different domestic sources of supply. Utility derived from the consumption of domestic composite goods is maximized. In the subsequent upper-level, substitution occurs between domestic composite and imported goods.

The model is structurally calibrated for 2004; a complete data set is available for that year, which is the year of the last publication of the full national input-output tables that served as the basis for the estimation of the interregional input-output database, facilitating the choice of the base year. Additional structural data from the period 2000–2004 complemented the database.

The CEER framework includes explicitly some important elements from an interregional system, needed to better understand macro spatial phenomena, namely: interregional flows of goods and services, transportation costs based on origin-destination pairs, interregional movement of primary factors, regionalization of the transactions of the public sector, and regional labour markets segmentation.

4.1 Structural database

The CGE core database requires detailed sectoral and regional information about the Colombian economy. National data (such as input-output tables, foreign trade, taxes, margins and tariffs) are available from the Colombian Statistics Bureau (DANE).[9] At the regional level, a full set of accounts was developed by the Colombian institute CEGA. These two sets of data were put

[9] Official statistics do not fully consider illegal activities in Colombia.

Table 2. Tariff rate and Armington elasticity, by product

Product	Tariff rate	Armington elasticity
AGR	8.8	1.05
MNE	0.9	1.28
IND	5.7	1.63
CNT	0.0	1.28
TRN	2.7	1.34
ADP	0.0	1.32
OTS	2.7	1.34

together in a balanced interregional social accounting matrix. Previous work in this task has been successfully implemented in CGE models for Brazil and Colombia (Haddad 1999; Jensen et al. 2004).

4.2 Behavioral parameters

Parameter values for international trade elasticities, σ s in Equation (A2) in Appendix, were taken from estimates from Ocampo et al. (2004); regional trade elasticities, σ s in Equation (A1), were set at the same values as the corresponding international trade elasticities (Table 2). Substitution elasticity between primary factors, σ s in Equation (A3), was set to 0.5. Scale economies parameters, μ s in Equation (A4), were set to one in all sectors and regions, except for the manufacturing sector in Bogotá, which was set to 0.8. The marginal budget share in regional household consumption, β s in Equation (A5), were calibrated from the Social Accounting Matrix (SAM) data, assuming the average budget share to be equal to the marginal budget share. We have set to –2.0 the export demand elasticities, η s in Equation (A9). Finally, we have assumed constant returns to bulk transportation, setting the parameter of scale economies in bulk transportation to one (θ s in Equation A12).

Further details of the model, including equation specification may be found in Haddad and Hewings (2005).

4.3 Closures

In order to capture the effects of trade liberalization, the simulations are carried out under two standard closures, referring to the short-run and the long-run. A distinction between the short-run and long-run closures relates to the treatment of capital stocks encountered in the standard microeconomic approach to policy adjustments. In the short-run closure, capital stocks are held fixed, while, in the long-run, policy changes are allowed to affect capital stocks. In addition to the assumption of interindustry and interregional immobility of capital, the short-run closure would include fixed regional population and labour supply, fixed regional wage differentials, and fixed national real wage. Regional employment is driven by the assumptions on wage rates, which indirectly determine regional unemployment rates. Labour is, thus, mobile only across sectors within the same region. On the demand side, investment expenditures are fixed exogenously – firms cannot reevaluate their investment decisions in the short-run. Household consumption follows household disposable income, and real government consumption, at both regional and central levels, is fixed (alternatively, the government deficit can be set exogenously, allowing government expenditures to change). Finally, preferences and technology variables are exogenous.

A long-run (steady-state) equilibrium closure is also used in which capital is mobile across regions and industries. Capital and investment are generally assumed to grow at the same rate. The main differences from the short-run are encountered in the labour market and the capital formation settings. In the first case, aggregate employment is determined by population growth, labour force participation rates, and the natural rate of unemployment. The distribution of the labour force across regions and sectors is fully determined endogenously. Labour is attracted to more competitive industries in more favoured geographical areas, keeping regional wage differentials constant. While in the same way, capital is oriented towards more attractive industries. This movement keeps rates of return at their initial levels.

5 Results

Trade liberalization is an important element of the range of structural changes foreseen by the Colombian government. To explore the effects of such policies, the CEER model is used to simulate the impacts of tariff changes in the Colombian economy. The model is applied to analyze the effects of a uniform 25% decrease in all tariff rates. All exogenous variables are set equal to zero, except the changes in the power of tariffs, i.e., one plus the tariff rates, which were set such that the percentage change decrease in each tariff rate was 25%. Results of the simulation computed via a four-step Euler procedure with extrapolation, under short-run and long-run closures, are presented in Tables 3–4 and 8–9; they show the percentage deviation from the base case (which is the situation without policy changes).[10] The analysis is concentrated on

Table 3. Short-run reffects on selected macro and sectoral variables

Real GDP	0.177
Real household consumption	0.483
Activity level	0.149
Employment: Persons	0.264
Unemployment rate (percentage point change)	–0.251
Nominal wage paid by producers	–0.336
GDP price index	–0.380
Consumer price index	–0.336
Export volume	0.380
Import volume	1.017
Balance of trade (percentage of GDP)	–0.174

Table 4. Short-run effects on sectoral activity (percentage change)

Sector	%
AGR	0.141
MNE	0.048
IND	0.050
CNT	0.019
TRN	0.282
ADP	–
OTS	0.227

[10] The model was implemented using the software GEMPACK (www.monash.edu.au/policy/gempack.htm).

the effects on spatial activity and welfare levels, and on some general macro variables.[11] Because of the nature of the data base, it should be pointed out that the model deals with changes in the real tariff rates (the ratio of import tax collected over the volume of imports), as opposed to nominal tariff rates, which are much higher. Moreover, the model does not consider non-tariff barriers. Thus, the real tariff rate in 2004 (benchmark year) was close to 5.5% as compared to the average nominal rate of over 10%. It is also important to note that the model takes into account differential sectoral tariff rates at the national level, and, given the specific regional import baskets, the overall tariff reduction produces asymmetric shocks in the regions.

5.1 Short-run

Table 3 summarizes the simulation short-run results on some macro variables. The real GDP of Colombia is shown to increase by 0.177% with all regions positively affected (Table 4), with real Gross Regional Product (GRP) increases ranging from 0.045% and 0.046% (Vaupés and Chocó, respectively) to 0.275% and 0.292% (Cundinamarca and Bogotá).

The results indicate that (industry) employment levels expand/contract in the same direction as activity levels. However, the expansions of these changes are more intense for employment: the value of the percentage change in employment (0.264%) is higher than the value of percentage change in activity level (0.149%). The explanation for the more intense change in the level of employment lies in the nature of the closure adopted in the simulation. It reflects the combined effects of fixed capital stocks and the general change in the price of hiring labour, which captures movements in the nominal wage paid to workers (–0.336%) relative to movements in the producers' product price (–0.380%). Thus, given the nature of the closure, which allows for producers to respond to exogenous shocks through changes in the employment level only, the employment figure reveals the short-run supply responses from the model, for a tariff decrease (0.264%).

Real household consumption increases by 0.483%, reflecting welfare gains as, with a fixed population, per capita real consumption also increases. In the CEER model, household consumption (in each region) is assumed to be a function of household disposable income. Since the national real wage is assumed fixed (nominal wages are indexed to the national CPI), this effect results directly from the increase in the activity level (employment effect). An examination of the national unemployment rates (which falls by 0.251 points) confirms this result.

Industry activity results show that, in general, nontradable sectors benefit most from the tariff cut, while import-competing sectors are the main relative losers. The manufacturing sector, which presents higher import substitution elasticities, higher import shares in their domestic markets, and higher percentage changes in their tariff rates (second after agriculture) is more likely to be harmed, in relative terms, by the policy change. Service sectors, that do not face strong competition from foreign products, tend to perform better in the short-run due to positive income effects.[12]

To better understand the short-run regional results of the model, a thorough analysis of the structure of the economy is needed. A close inspection on the benchmark data base is necessary,

[11] The volume of information that the model produces in each simulation is overwhelming. To interpret the results, the study tries to focus the analysis on a few interesting issues associated with the respective simulations, in order to rationalize particular results in terms of the model's theoretical framework and its underlying data base. This process, apart from giving insights into a particular economic phenomenon, serves to act as an informal verification of the simulations' results.

[12] In the short run closure, the assumption on fixed government demand is reflected in the public administration result.

Table 5. Short-run effects on selected spatial variables

		GRPP	Activity level	Equivalent variation
D1	Antioquia	0.136	0.112	364,628
D2	Atlántico	0.147	0.135	112,651
D3	Bogotá D. C.	0.292	0.262	1,187,467
D4	Bolívar	0.113	0.093	86,795
D5	Boyacá	0.156	0.113	62,240
D6	Caldas	0.106	0.106	28,371
D7	Caquetá	0.052	0.053	3,184
D8	Cauca	0.064	0.053	19,940
D9	Cesar	0.115	0.110	30,169
D10	Córdoba	0.131	0.100	76,318
D11	Cundinamarca	0.275	0.258	214,639
D12	Chocó	0.046	0.042	3,805
D13	Huila	0.055	0.051	15,576
D14	La Guajira	0.110	0.100	33,038
D15	Magdalena	0.153	0.146	27,142
D16	Meta	0.121	0.115	26,222
D17	Nariño	0.119	0.090	33,091
D18	Norte Santander	0.105	0.097	24,256
D19	Quindío	0.087	0.086	8,416
D20	Risaralda	0.097	0.089	28,357
D21	Santander	0.198	0.132	286,486
D22	Sucre	0.084	0.083	7,527
D23	Tolima	0.101	0.090	33,516
D24	Valle	0.117	0.107	226,986
D25	Amazonas	0.064	0.065	533
D26	Arauca	0.274	0.139	11,584
D27	Casanare	0.060	0.061	28,015
D28	Guanía	0.054	0.053	301
D29	Guaviare	0.116	0.124	1,218
D30	Putumayo	0.092	0.092	2,811
D31	San Andrés y Providencia	0.181	0.174	4,878
D32	Vaupés	0.045	0.047	159
D33	Vichada	0.167	0.174	1,552

conducted not only on the relationships in the interregional input-output data base, but also on the other relevant structural parameters of the model. As shown in Haddad et al. (2002), structural coefficients derived from the SAM lead short-run results in less flexible environments (closures). As one precludes factor mobility to a great extent, understanding of disaggregated results may be achieved through econometric regressions on key structural coefficients.

How important is the existing economic structure in explaining the short-run spatial results associated with a trade liberalization policy in Colombia? Do backward and forward linkages matter? To answer these questions, following Dixon et al. (1982, 2007), the model results (GRP, activity level and equivalent variation) presented in Table 5 are regressed against selected structural coefficients of the model (figures available from the authors on request). The OLS regressions are shown in Tables 6 to 8, and aim only at revealing the influence of the benchmark structure on the short-run results.

According to the results for GRP and regional activity level, Tables 6 and 7, structural indicators explain 74 and 76%, respectively, of the variation across departments in the CEER model results. These results go in the same direction (correlation of 92.08%), as can be visually

Table 6. Structural analysis of short-run GRP results

Dependent variable: PIB_SR				
Variable	Coefficient	Std. error	t-statistic	Prob.
Constant	−0.239680	0.102458	−2.339312	0.0270
IMPSHTOT	0.361736	0.105921	3.415145	0.0020
SH_1	0.434683	0.128793	3.375053	0.0022
SH_3	0.459034	0.153107	2.998128	0.0058
SH_4	0.642070	0.124899	5.140696	0.0000
MNE	−0.314800	0.059138	−5.323118	0.0000
R-squared	0.744891			

Notes: PIB_SR = percentage change in GRP; IMPSHTOT = import penetration in total consumption; SH_1 = intermediate inputs share in total sales; SH_3 = household share in total sales; SH_4 = export share in total sales; MNE = share of mining in total output.

Table 7. Structural analysis of Short-run activity level results

Dependent variable: ACT_SR				
Variable	Coefficient	Std. Error	t-Statistic	Prob.
Constant	−0.157437	0.083251	−1.891106	0.0698
IMPSH_3	−0.666530	0.342087	−1.948421	0.0622
IMPSHTOT	1.310548	0.430980	3.040852	0.0053
SH_1	0.390297	0.106954	3.649206	0.0012
SH_3	0.370619	0.124310	2.981411	0.0062
SH_4	0.407252	0.095772	4.252299	0.0002
KL	−0.064311	0.020033	−3.210213	0.0035
R-squared	0.758846			

Notes: ACT_SR = percentage change in regional activity level; IMPSH_3 = import penetration in household consumption; IMPSHTOT = import penetration in total consumption; SH_1 = intermediate inputs share in total sales; SH_3 = household share in total sales; SH_4 = export share in total sales; KL = capital to labour ratio.

Table 8. Structural analysis of short-run equivalent variation results

Dependent Variable: EV_SR				
Variable	Coefficient	Std. Error	t-Statistic	Prob.
Constant	101,092.5	29,728.72	3.400500	0.0020
IMPSH_1	−14,102,528	2,096,919.	−6.725356	0.0000
IMPSH_2	6,023,651	916,107.7	6.575266	0.0000
IMPSH_3	12,497,712	2,030,318.	6.155545	0.0000
NONCON	−311,691.1	125,681.9	−2.479999	0.0194
R-squared	0.828179			

Notes: EV_SR = change in regional equivalent variation; IMPSH_1 = import penetration in intermediate consumption; IMPSH_2 = import penetration in capital goods consumption; IMPSH_3 = import penetration in household consumption; NONCON = share of non-consumer goods in total output.

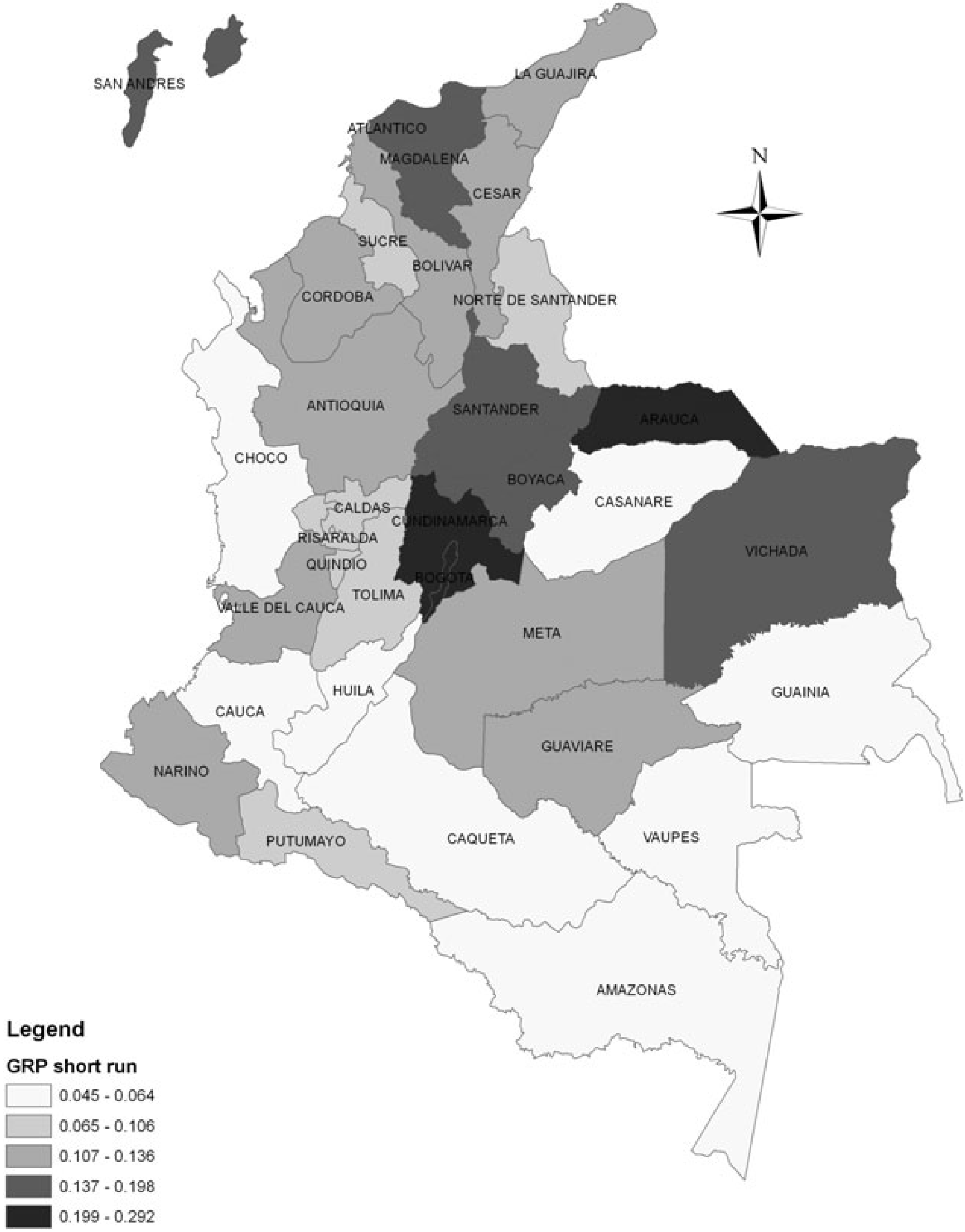

Fig. 3. Short-run effects on GRP

perceived in Figures 3 and 4. Regional GRP/activity results show that, in general, Departments in the dynamic core of the country tend to benefit most from the tariff cut, while peripheral regions are the main losers in the short-run. Explanations for specific regional results should consider structural and parametric aspects of the data base. Regions that present higher increases in their output tend to have an overall higher share of imports, benefiting from lower cost of imported inputs; however the higher the share of imports in final consumption (households), the

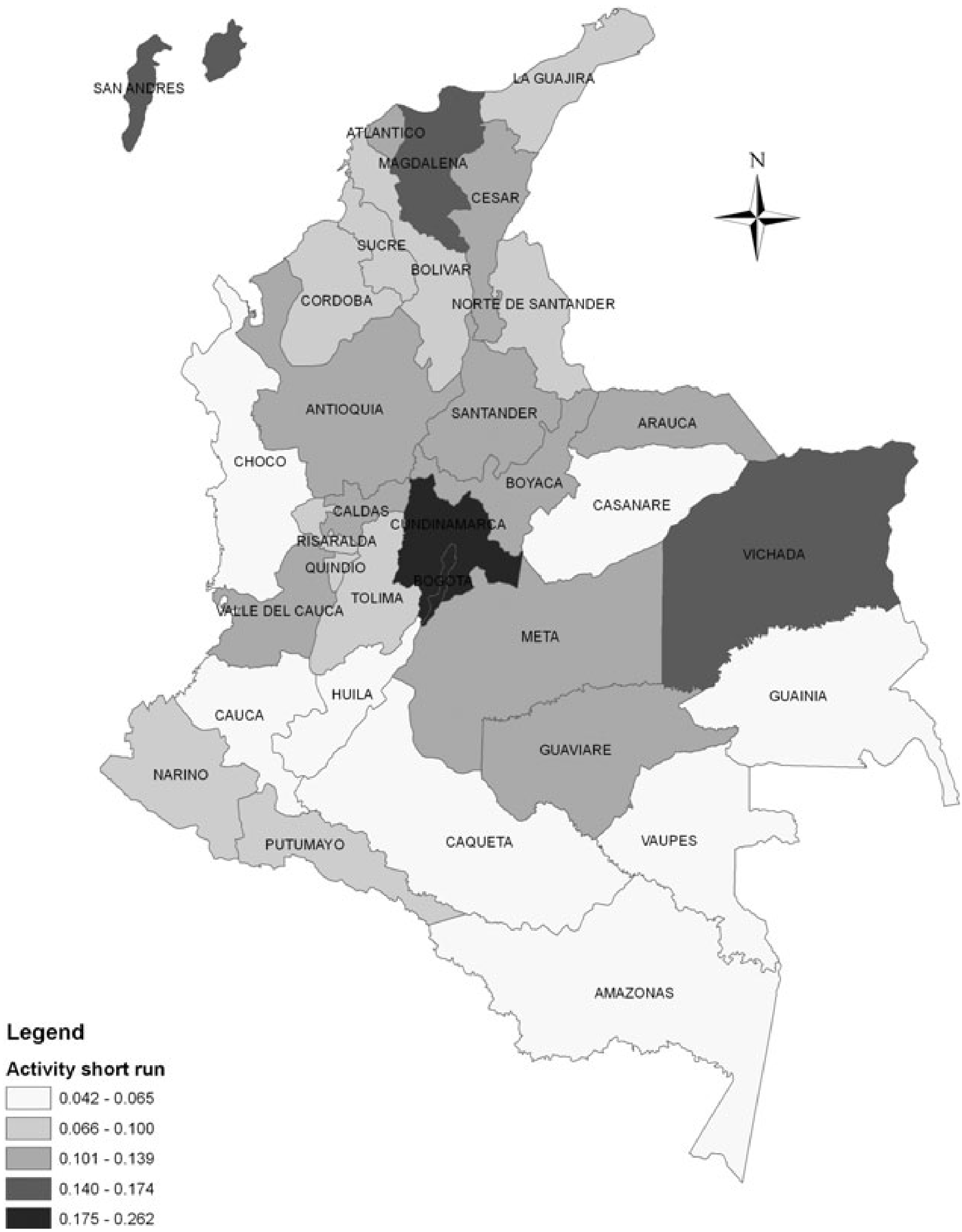

Fig. 4. Short-run effects on activity level

lower the benefit to increase output in the region, as substitution effects at this stage of the chain do not translate into cost advantages (Table 7). Also, regions that face stronger positive effects tend to concentrate their sales to other sectors (intermediate inputs), to households, or to foreign consumers. A higher capital/labour ratio seems to hamper economic performance in the short-run, as employment expansion turns out to be less feasible. Specifically in terms of GRP effects, regions with a high share of the mining sector in their output are more likely to be harmed by

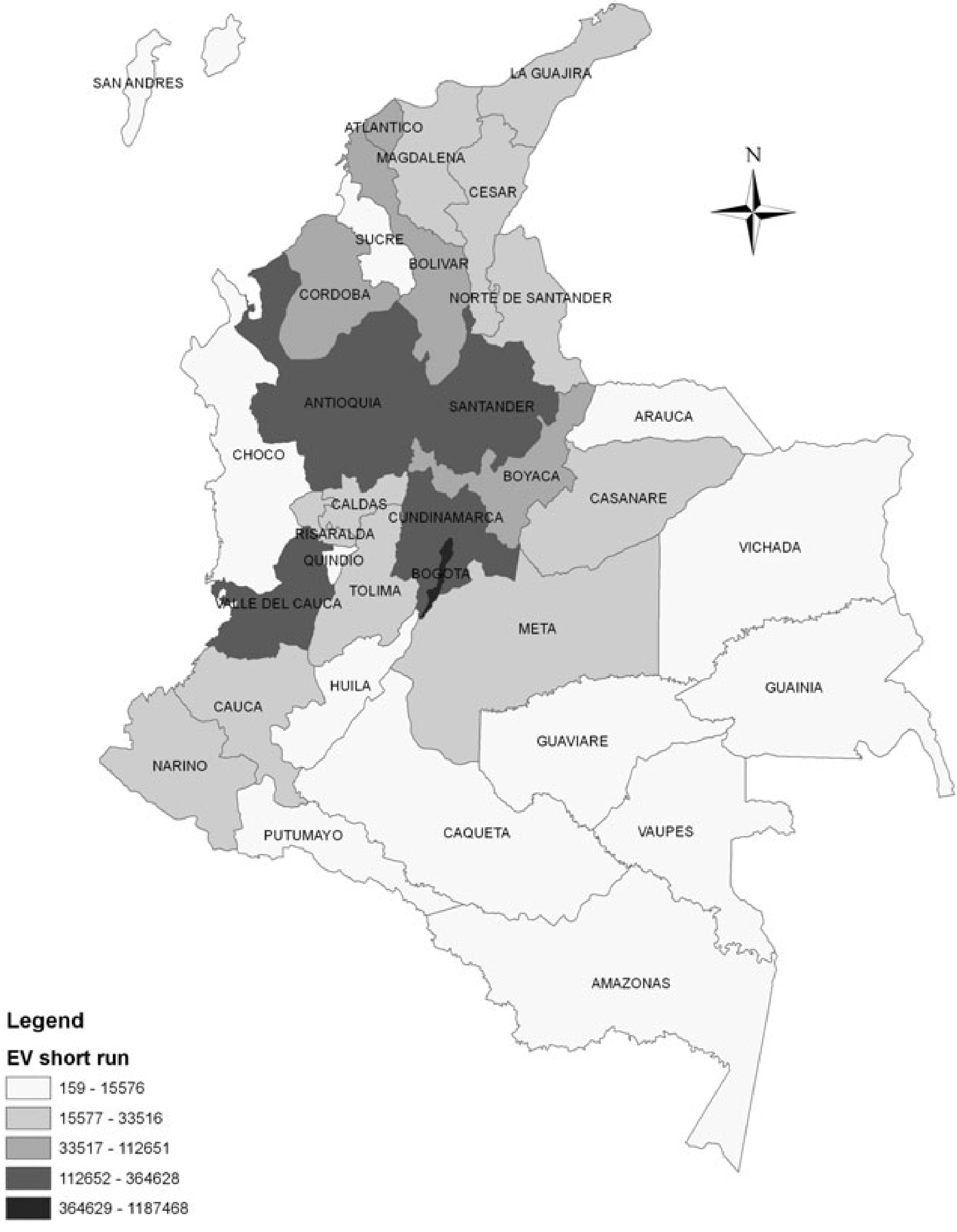

Fig. 5. Short-run effects on equivalent variation

the policy change. In the case of the model results for welfare (Figures 5 and 6), measured in terms of (relative) equivalent variation, the core region also benefits from the shock, both in absolute (EV) and relative terms (REV[13]).

[13] Relative equivalent variation is measured by the ratio of the equivalent variation to pre-shock regional household disposable income.

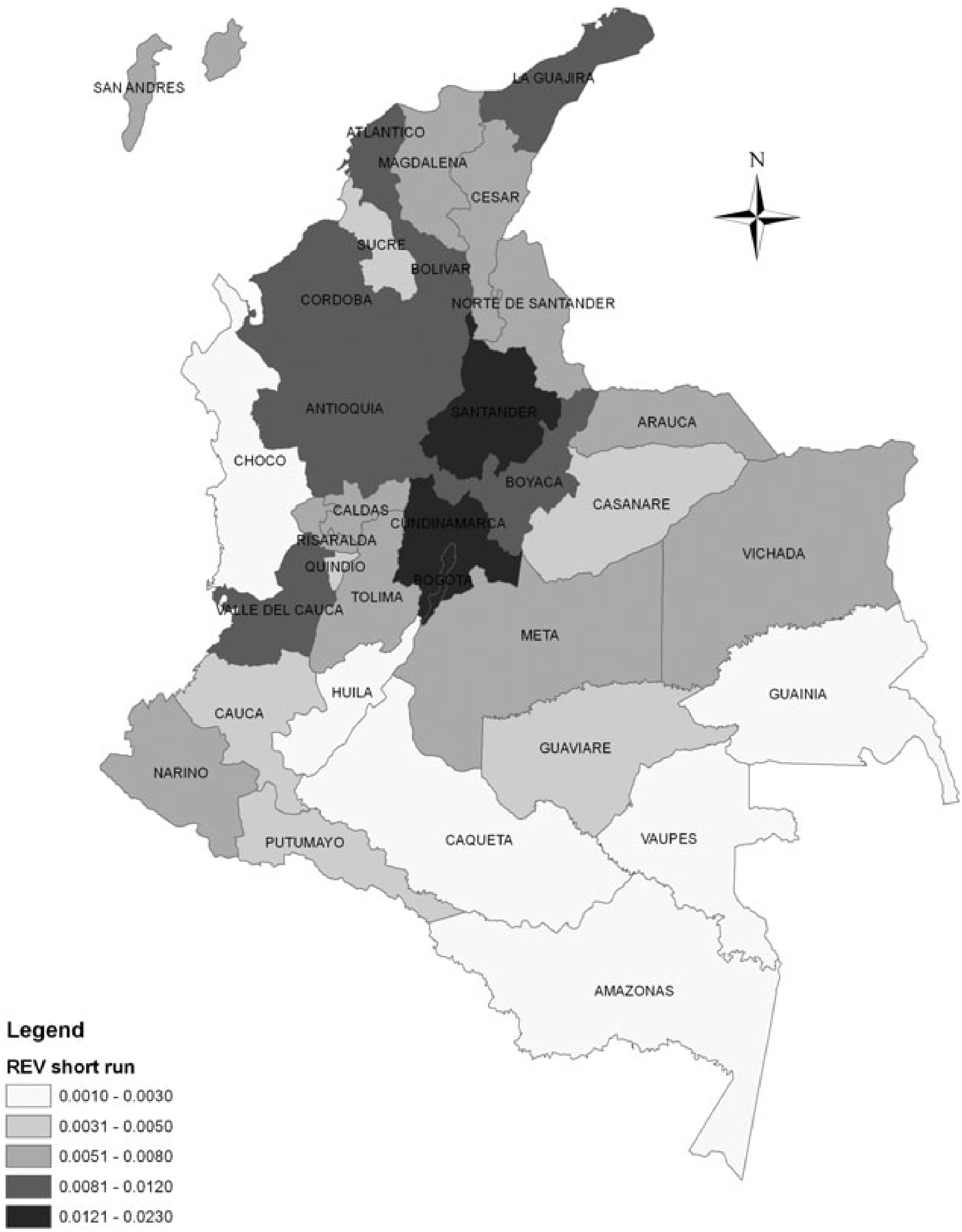

Fig. 6. Short-run effects on relative equivalent variation

The specification of the household demand system in the CEER model allows the computation of measures of welfare. More specifically, one can calculate the equivalent variation (EV) associated with a policy change. The equivalent variation is the amount of money one would need to give to an individual, if an economic change did not happen, to make him as well off as if it did (Layard and Walters 1978). The Hicksian measure of EV would consider computing the hypothetical change in income in prices of the post-shock equilibrium (Bröcker and Schneider

2002). Alternatively, it can be measured as the monetary change of benchmark income the representative household would need in order to get a post-simulation utility under benchmark prices. Another informative welfare measure refers to the relative equivalent variation (REV). It is defined as the percentage change of benchmark income the representative household would need in order to get a post-simulation utility under benchmark prices (Bröcker 1998).

Given the nature of the welfare measures, the relevant structural coefficients to explain regional performance identified in Table 8 seem plausible. In the short-run, regions with higher shares of imports in final consumption (households) would receive greater welfare gains. The intuition here is that lower tariff rates would result in a greater volume of goods being available at lower prices in the regions. Regions presenting high import shares of capital goods also tend to face welfare gains, through indirect effects in the consumption of (durable) consumer goods. On the other hand, regions that depend more on imported inputs and whose economic structures are more concentrated in the output of non-producer goods are negatively affected.

5.2 Long-run

The results described above refer to the short-run effects of the tariff reduction, which are important for macroeconomic management. As trade reform aims at improving the allocation of resources in the long term, a simulation was carried out adopting a long-run closure, in the realm of new economic geography models. In this exercise, the assumptions on interregional mobility of capital and labour are relaxed and a steady-state-type of solution is achieved, in which regional natural unemployment rates and regional aggregate rates of return are reestablished. Moreover, balance of payment equilibrium is reflected in the hypothesis of fixed share of trade balance in GDP. From a spatial perspective, in the long-run the 're-location' effect becomes relevant; as factors are free to move between regions, new investment decisions define marginal re-location of activities, in the sense that the spatial distribution of capital stocks and the population changes. In what follows, attention will be focused on results usually discussed in the NEG literature, presented in Section 3.

Table 9 shows the long-run results of the simulation for selected national variables. As the aggregate level of employment is now assumed exogenously determined by demographic variables, the national real wage is allowed to change to keep national employment in the base case level. Supply-side effects are restricted to the distribution of labour across sectors and regions, and to capital movements. At the national level, the increase in GDP by 0.027% above the base case level is possible through the increase in the capital stock of the economy (0.149%)

Table 9. Long-run effects on selected macro variables (percentage change)

Real GDP	0.027
Real household consumption	–0.269
Real investment	0.937
Capital stock	0.149
Activity level	0.043
Regional government consumption	–0.168
Central government consumption	–0.269
Consumer price index	0.326
International export volume	0.704
International import volume	0.349
Balance of trade (percentage of GDP)	–
Nominal wage	–0.416
GDP price index	0.319

Table 10. Long-run effects on sectoral activity (percentage change)

Sector	%
AGR	0.332
MNE	0.374
IND	0.140
CNT	0.849
TRN	–0.117
ADP	–0.244
OTS	–0.135

induced by the initial fall in the aggregate rental price of capital. Imported commodities are important inputs for capital creation and the fall in the prices of imports reduces the cost of producing capital. The hypothesis of fixed trade balance share in GDP together with low export elasticities are accompanied by reductions in the real wage to make exports more competitive. With lower real wages, household disposable income goes down in real terms, inducing a decrease in the real household consumption. As regional government consumption of public goods is assumed to move with regional household consumption, and central government consumption of public goods follows the national household consumption level, domestic absorption is leveraged only by real investments. As a consequence, real GDP growth is smaller than in the short-run.

From a sectoral perspective, long-run results clearly benefit the tradable-good sectors as well as investment-related activities (mainly construction). Estimates presented in Table 10 show that there is a shift in the Colombian economic structure towards agriculture, mining, manufacturing and construction, at the expense of service sectors.

Regional unemployment and wage differentials are assumed constant in the simulation. The CEER model accommodates the labour market assumptions by allowing population movements between regions so that labour supply is increased in regions experiencing employment expansion, and vice-versa. The impact of the trade liberalization policy favours activity levels outside Bogotá, especially in its vicinity, at the expense of the main economic centre, with a consequent transfer of population from the latter (Figure 7).

In the long-run, producers are able to reevaluate their investment decisions, which was not possible in the short-run. The short-run movements in the rental values of capital and cost of capital define differential rates of returns in each sector, providing indicators of more profitable investment opportunities. Current rates of return are defined by the ratio of the rental values of a unit of capital (that depends on the productivity of the current capital stock in each industry) and the cost of a unit of capital, based on its cost structure. The CEER model assumes that if the percentage change in the rate of return in a regional industry grows faster than the national average rate of return, capital stocks in that industry will increase at a higher rate than the average national stock. For industries with lower-than-average increase in their rates of return to fixed capital, capital stocks increase at a lower-than-average rate, namely, capital is attracted to higher return industries.

The role of price changes proves to be very important in understanding the net results, in real terms in the components of GRP, in the different departments (Table 11). Regions that do not face strong price changes benefit more from real growth, as they perceive gains in relative efficiency. From a spatial perspective, there appears to be a de-concentration pattern from Bogotá to its vicinity. It is noteworthy that movements within the extended core region of the Colombian economy tend to go towards the coast. This 'coastal effect' relates also to the cost structure of the regional economies. Given their location closer to external markets, the relative

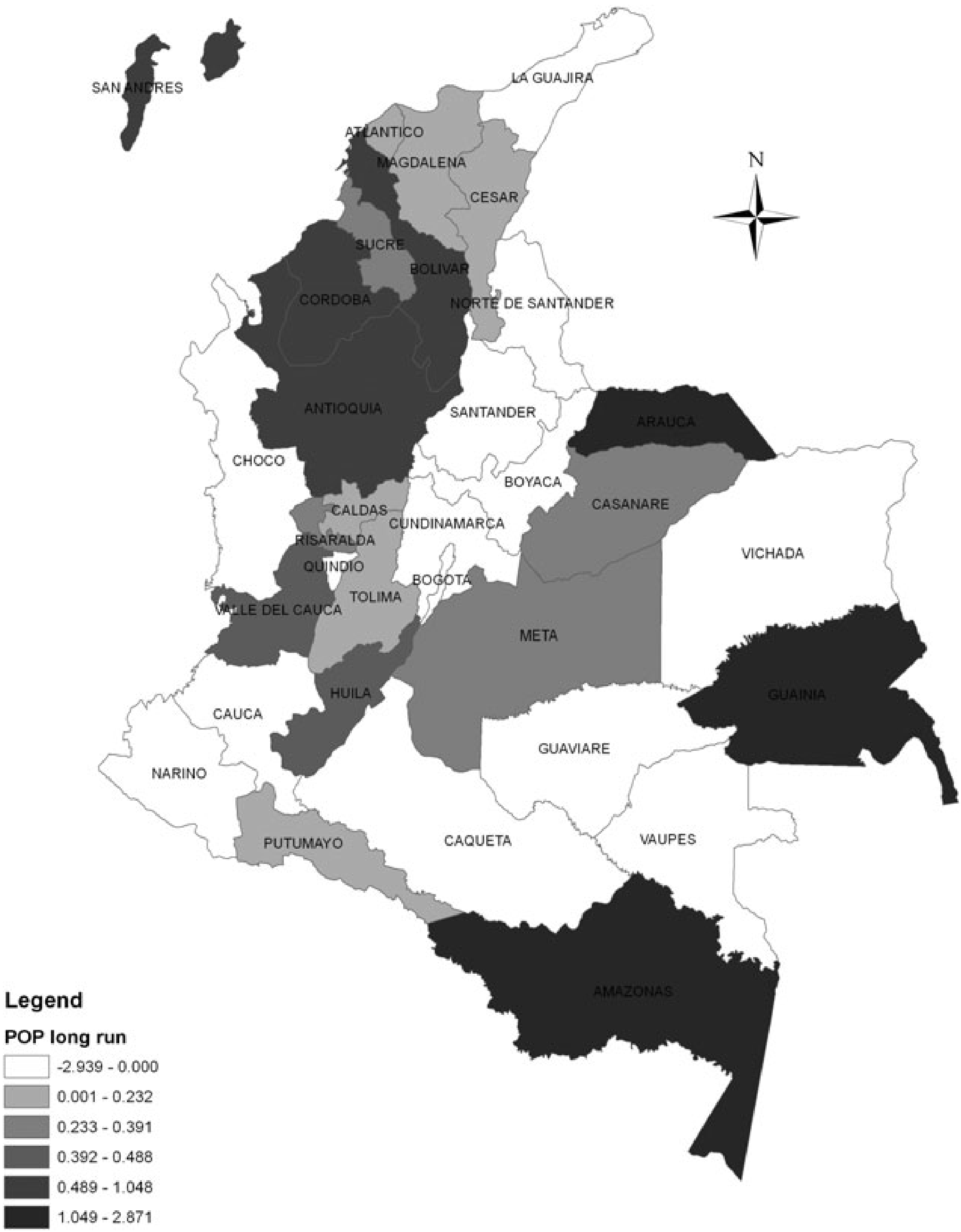

Figure 7. Long-run effects on population growth

importance of tariffs to these regions is greater, as they face lower internal transportation costs to the ports of entry/exit.[14] Thus, market accessibility is one of the elements that implicitly drive the spatial activity results in the long-run (Figures 8 and 9).

[14] Differential spatial cost structures associated with import flows are considered in the calibration of the model, as imported goods are assigned internal transportation costs from the port of entry to the place of consumption (likewise for export goods).

Table 11. Long-run effects on GRP components (% change)

		Household	Investment	Regional Govt	Central Govt	Regional		International		GRP	GRP deflator	CPI
						Exports	Imports	Exports	Imports			
D1	Antioquia	0.652	4.422	0.652	–0.269	–0.184	1.124	1.027	2.012	0.927	0.485	0.280
D2	Atlántico	–0.049	1.178	–0.049	–0.269	0.256	–0.014	1.100	1.260	0.187	0.213	0.258
D3	Bogotá D.C.	–0.507	–0.081	–0.507	–0.269	–0.275	–0.298	0.528	0.050	–0.551	0.604	0.458
D4	Bolívar	0.228	4.049	0.228	–0.269	0.539	0.411	1.284	1.711	0.637	–0.137	0.138
D5	Boyacá	–1.489	–4.140	–1.489	–0.269	0.163	–1.402	0.682	–0.316	–0.611	–0.209	0.458
D6	Caldas	–0.181	–0.285	–0.181	–0.269	0.274	–0.163	1.386	0.590	0.100	–0.064	0.103
D7	Caquetá	–1.057	–6.147	–1.057	–0.269	–0.086	–1.643	0.939	–0.825	–0.768	–0.077	0.261
D8	Cauca	–0.897	–3.829	–0.897	–0.269	0.355	–1.097	1.142	–0.218	–0.682	0.002	0.205
D9	Cesar	–0.064	3.006	–0.064	–0.269	–0.152	0.296	0.566	1.523	0.267	0.428	0.297
D10	Córdoba	0.171	2.658	0.171	–0.269	0.557	0.678	1.522	0.584	0.750	–0.204	–0.034
D11	Cundinamarca	–1.233	–0.314	–1.233	–0.269	–1.205	–0.254	0.036	–0.081	–0.936	1.383	0.929
D12	Chocó	–2.028	–6.091	–2.028	–0.269	–0.078	–2.912	–1.312	–0.848	–1.965	0.775	0.669
D13	Huila	0.051	1.520	0.051	–0.269	0.099	0.298	0.967	0.374	0.444	–0.210	0.035
D14	La Guajira	0.061	3.797	0.061	–0.270	–0.013	0.554	0.314	0.832	0.247	0.601	0.263
D15	Magdalena	–0.240	–1.488	–0.240	–0.269	0.097	–0.572	1.819	0.734	0.019	–0.173	0.156
D16	Meta	–0.113	1.293	–0.113	–0.269	–0.012	–0.009	0.846	–0.014	0.321	–0.203	0.053
D17	Nariño	–0.262	–0.344	–0.262	–0.269	0.227	–0.339	1.064	0.871	0.046	–0.039	0.177
D18	Norte Santander	–0.451	–2.122	–0.451	–0.269	0.407	–0.675	0.815	0.430	–0.122	–0.149	0.179
D19	Quindío	–0.419	–1.840	–0.419	–0.269	0.334	–0.575	1.294	–0.054	–0.150	–0.165	0.114
D20	Risaralda	0.064	1.188	0.064	–0.269	0.304	0.258	1.232	1.402	0.320	0.156	0.170
D21	Santander	–1.160	–1.635	–1.160	–0.269	0.393	–0.742	0.847	–0.157	–0.440	–0.181	0.186
D22	Sucre	–0.032	0.132	–0.032	–0.269	0.613	0.058	1.211	0.125	0.259	–0.138	0.148
D23	Tolima	–0.498	–0.984	–0.498	–0.269	0.268	–0.501	0.637	0.724	–0.064	–0.148	0.217
D24	Valle	0.061	1.852	0.061	–0.269	0.373	0.167	1.305	0.873	0.364	–0.019	0.164
D25	Amazonas	0.787	–5.605	0.787	–0.269	0.119	–0.422	4.969	0.229	1.316	–3.387	–0.612
D26	Arauca	1.626	9.318	1.626	–0.269	–0.229	2.181	1.628	3.277	1.440	–0.141	0.088
D27	Casanare	0.030	1.939	0.030	–0.269	–0.048	0.494	0.286	1.645	0.261	0.700	0.509
D28	Guanía	1.492	7.306	1.492	–0.269	0.206	1.794	5.841	0.090	2.225	–1.988	–0.489
D29	Guaviare	–3.107	–13.803	–3.107	–0.269	–0.564	–3.876	–2.556	–2.035	–2.759	1.270	0.841
D30	Putumayo	–0.417	–0.199	–0.417	–0.269	0.209	–0.405	0.609	–0.346	0.053	–0.118	0.186
D31	San Andrés y Providencia	0.193	3.186	0.193	–0.269	0.698	0.493	1.677	0.129	0.538	–0.152	0.159
D32	Vaupés	–0.798	–3.835	–0.798	–0.269	0.036	–0.720	0.149	–0.417	–0.640	0.519	0.144
D33	Vichada	–1.500	–8.927	–1.500	–0.269	–0.322	–1.804	–0.305	–1.401	–1.201	0.183	0.289
	National	–0.269	0.937	–0.168	–0.269	0.000	0.000	0.704	0.490	0.270	0.319	0.360

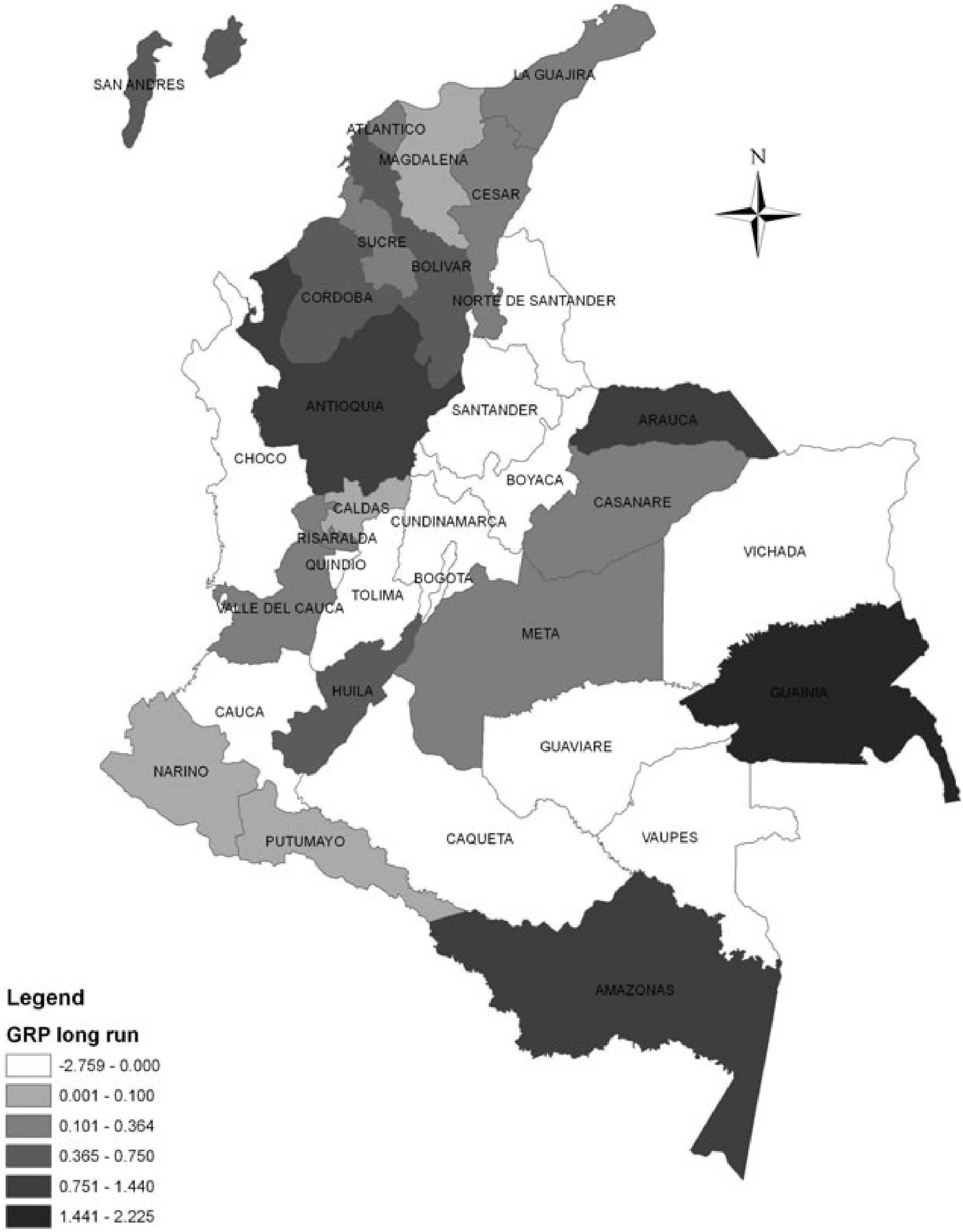

Fig. 8. Long-run effects on GRP

As for welfare (Figures 10 and 11), the measures used in the model reflect also congestion effects in the long-run, as they impose a penalty to population growth.[15] Regions that present better indicators for welfare, in relative terms (REV), are those regions that face reductions in

[15] In the equation for equivalent variation the relevant argument is the variable utility per household. As the number of households in each region follows population change, in-migrants will negatively impact on welfare, increasing congestion costs in the region.

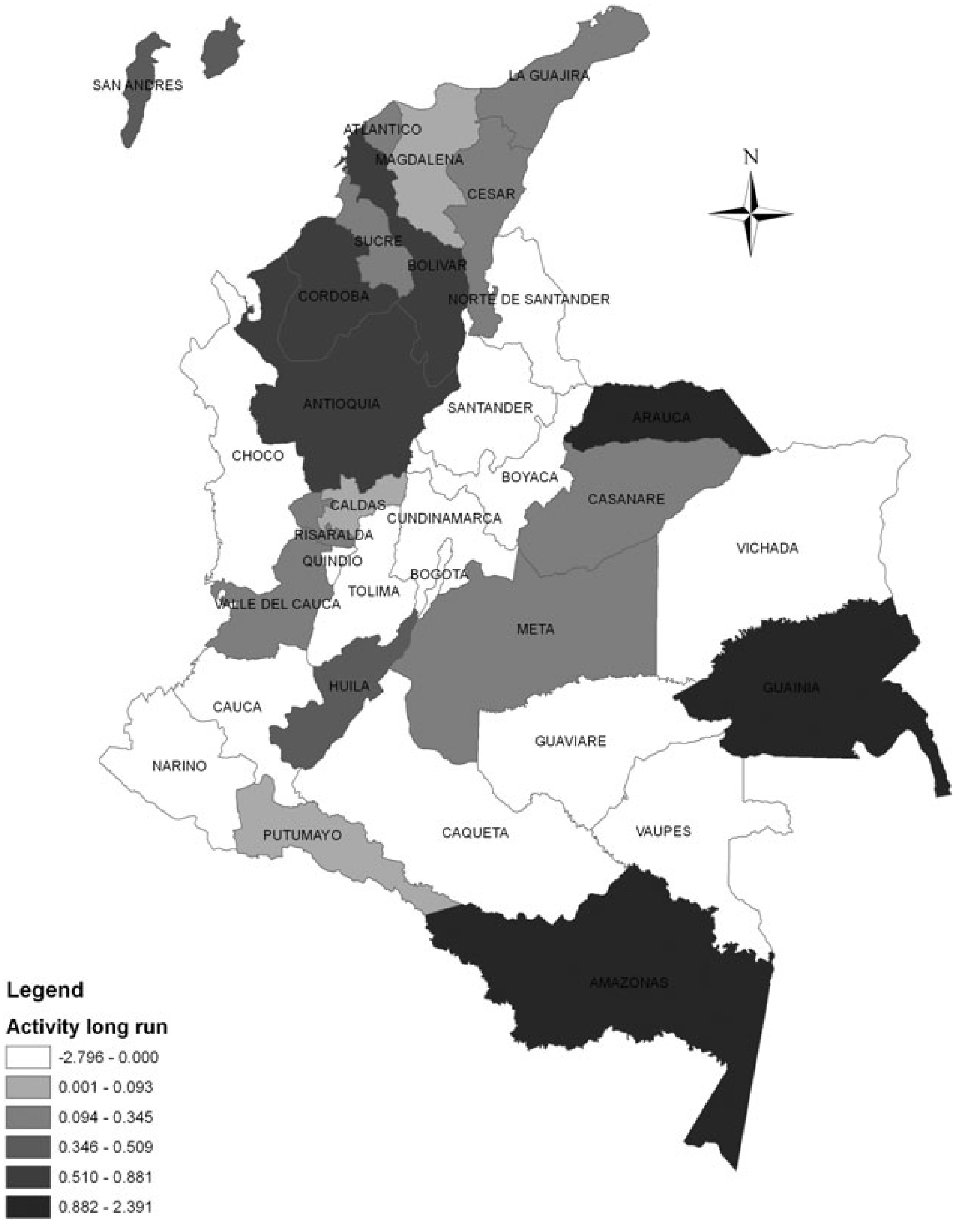

Fig. 9. Long-run effects on activity level

congestion costs, measured in terms of population change.[16] The spatial pattern that arises reveals welfare improvement only in Bogotá and a few peripheral departments, further away from the Colombian economic core.

[16] Correlation of –97.7% between the results for population change and relative equivalent variation, in the long-run.

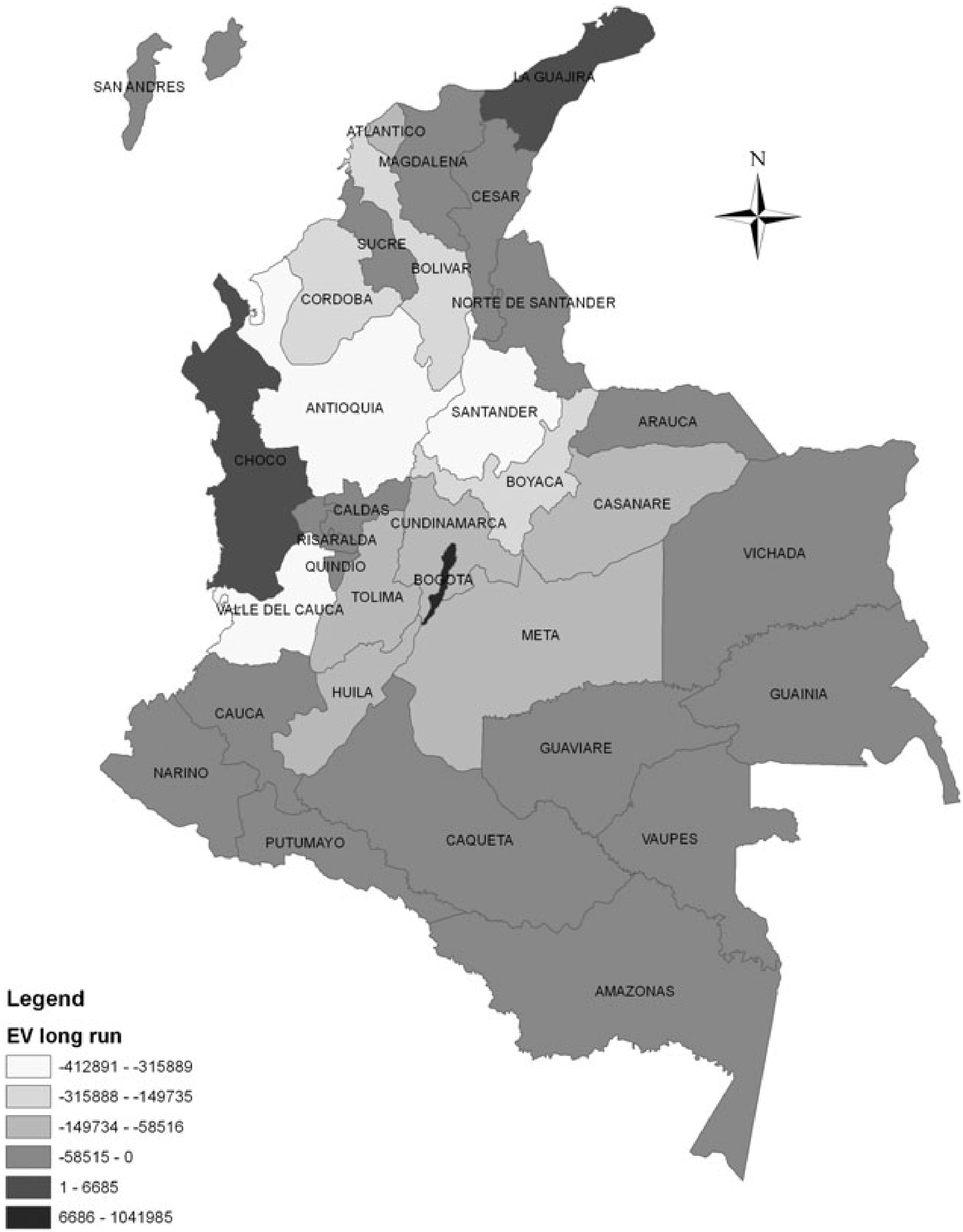

Fig. 10. Long-run effects on equivalent variation

Finally, the impact on regional specialization was analysed. As has been noted, one of the main results of the NEG literature on the effects of trade liberalization is that regions become more specialized. To look at this issue, the regional coefficients of specialization (Isard 1960), was calculated using the benchmark database and the post-simulation updated database. The Departments that presented increases in their coefficients of specialization after the trade liberalization experiment (in Figure 12 those regions in dark tint) were then identified. Together,

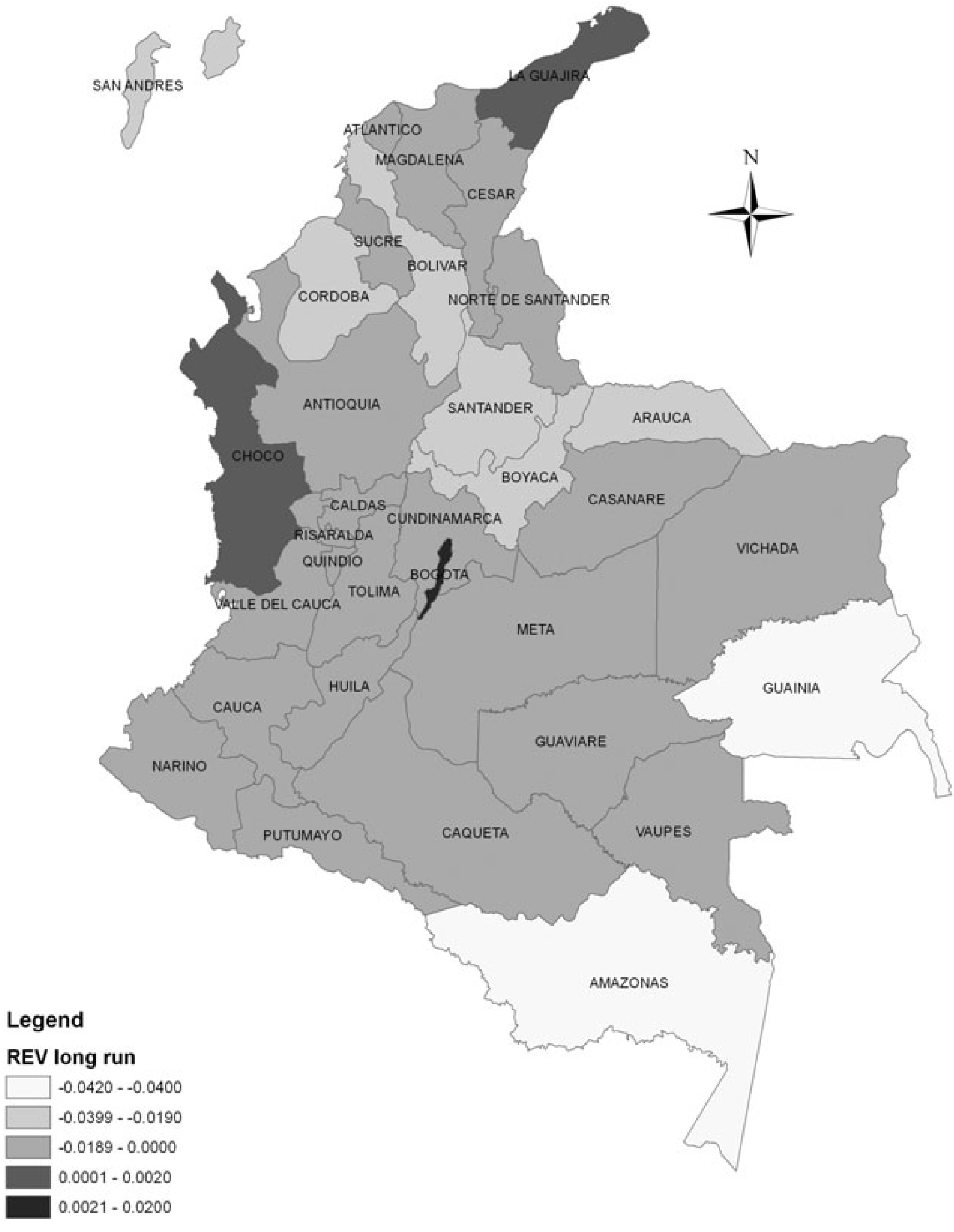

Fig. 11. Long-run effects on relative equivalent variation

these departments are responsible for close to 75% of total output in Colombia. Given the nature of the coefficient – which compares two percentage distributions measuring the extent to which the distribution of output by sector in a given region deviate from such distribution for Colombia – the fact that the bigger regions become more specialized suggests that Colombian regions, in general, become more specialized. This result supports theoretical findings in the NEG literature.

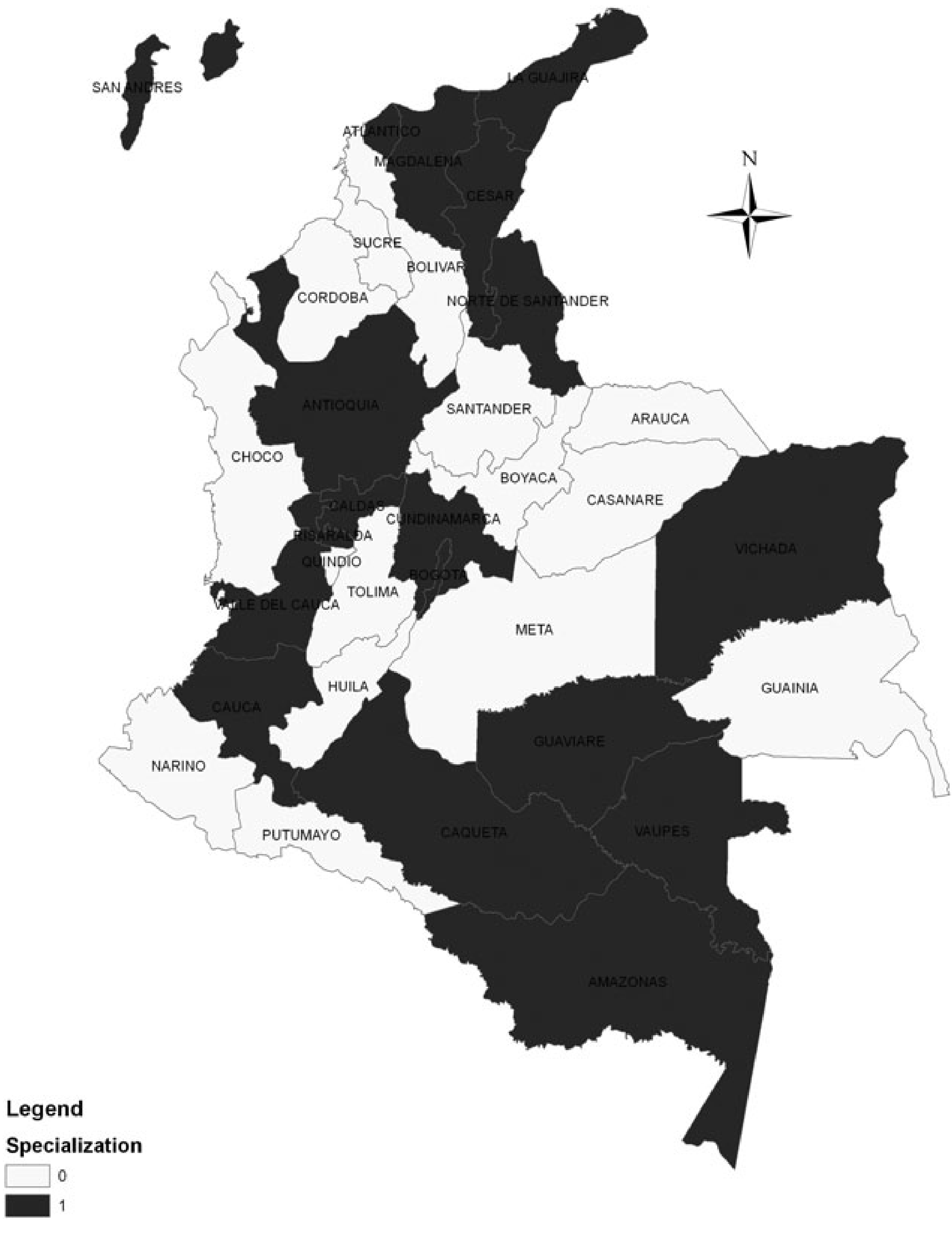

Fig. 12. Long-run effects on regional specialization (1 = more specialized)

5.3 Systematic sensitivity analysis

How sensitive are the results to parameter specification? In this sub-section, sensitivity analysis for key parameters is performed, providing a more reliable range of model results. Given the nature of the simulations, key parameters are represented by the export demand elasticities and the regional/international trade elasticities (Armington elasticities). Experience with spatial

CGE modelling has suggested that interregional substitution is the key mechanism that drives the model's spatial results. In general, interregional linkages play an important role in the functioning of interregional CGE models. These linkages are driven by trade relations (commodity flows), and factor mobility (capital and labour migration). In the first case, of direct interest to our exercise, interregional trade flows should be incorporated in the model. Interregional input-output databases are required to calibrate the model, and regional trade elasticities play a crucial role in the adjustment process. Moreover, from a spatial perspective, the role of scale parameters in the manufacturing sectors should also be assessed.

The scenarios related to the tariff cut experiments discussed above were employed using the Gaussian quadrature[17] approach to establish confidence intervals for the main results. The range for the parameters in the first group of sensitivity analyses was set to +/− 25% around the default values, with independent, symmetric, triangular distributions for three sets of parameters, namely the export demand elasticities for the various products, η s in Equation (A9) in the Appendix, and Armington elasticities of substitution between goods from different domestic regions, σ s in Equation (A1), and between imported and domestic goods, σ s in Equation (A2).

The second group of sensitivity analyses was carried out in the scale economies parameters in the regional manufacturing sectors, μ s in Equation (A4), using a similar range around the default values (+/− 25%).

Table 12 summarizes the sensitivity of GRP results in each Colombian territorial unit, as well as for the country as a whole, for the ranges in the two sets of parameters, both in the short-run and long-run scenarios. The lower bound and the upper bound columns represent the 90% confidence intervals for the estimates, constructed using Chebyshev's inequality. We observe that, in general, aggregate GRP results are relatively more robust to scale economy parameters than to trade elasticities both in the short-run and in the long-run. Overall, the territorial results can be considered to be more robust to both sets of parameters in the short-run closure.[18]

6 Final remarks

This paper has offered some preliminary steps in the marriage of some of the theoretical foundations of new economic geography with spatial computable general equilibrium models. Modelling the spatial economy of Colombia using the traditional assumptions of CGE models makes little sense when one territorial unit, Bogotá, accounts for over one quarter of GDP and where transportation costs are high and accessibility low compared to European or North American standards. Hence, handling market imperfections becomes imperative as does the need to address internal spatial issues from the perspective of Colombia's increasing involvement with external markets. The paper built on the CEER model, a spatial CGE model of the Colombian economy with non-constant returns and non-iceberg transportation costs.

The results of tariff cut simulations confirmed the asymmetric impacts that trade liberalization has on a spatial economy in which one region, Bogotá, is able to more fully exploit scale economies *vis-à-vis* the rest of Colombia. The analysis also revealed the importance of different

[17] The Gaussian quadrature (GQ) approach (Arndt 1996; DeVuyst and Preckel 1997), used in this exercise, was proposed to evaluate CGE model results' sensitivity to parameters and exogenous shocks. This approach views key exogenous variables (shocks or parameters) as random variables with associated distributions. Due to the randomness in the exogenous variables, the endogenous results are also random; the GQ approach produces estimates of the mean and standard deviations of the endogenous model results, thus providing an approximation of the true distribution associated with the results.

[18] In the long run there appear (a few) cases with qualititative changes (changes in sign) within the confidence interval, especially for smaller regions.

Table 12. Systematic sensitivity analysis: GRP/GDP changes (%)

		Trade elasticities				Scale economies parameters			
		Short-run		Long-run		Short-run		Long-run	
		Lower bound	Upper bound	Lower bound	Upper bound	Lower bound	Upper bound	Lower bound	Upper bound
D1	Antioquia	0.13106	0.14167	0.84223	1.01114	0.13437	0.13836	0.90154	0.95183
D2	Atlántico	0.14105	0.15212	0.17045	0.20303	0.14647	0.14670	0.17966	0.19381
D3	Bogotá D. C.	0.27741	0.30735	−0.57592	−0.52666	0.29072	0.29404	−0.57735	−0.52523
D4	Bolívar	0.10766	0.11905	0.56298	0.71104	0.11315	0.11355	0.62688	0.64713
D5	Boyacá	0.14578	0.16566	−0.69320	−0.52807	0.15310	0.15834	−0.67065	−0.55061
D6	Caldas	0.09895	0.11313	0.07267	0.12802	0.10589	0.10619	0.08606	0.11463
D7	Caquetá	0.03958	0.06512	−0.86085	−0.67442	0.05115	0.05354	−0.78556	−0.74971
D8	Cauca	0.05733	0.07111	−1.61065	0.24679	0.06420	0.06424	−0.87050	−0.49336
D9	Cesar	0.11146	0.11908	0.22671	0.30767	0.11359	0.11694	0.24758	0.28680
D10	Córdoba	0.12454	0.13707	0.68171	0.81830	0.12883	0.13279	0.71318	0.78683
D11	Cundinamarca	0.25878	0.29208	−1.18673	−0.68512	0.25609	0.29476	−1.10418	−0.76767
D12	Chocó	0.04031	0.05150	−6.00005	2.06926	0.04501	0.04680	−2.61918	−1.31161
D13	Huila	0.04998	0.05944	0.17573	0.71194	0.05346	0.05596	0.38752	0.50015
D14	La Guajira	0.10622	0.11351	0.19313	0.30085	0.10878	0.11095	0.22695	0.26703
D15	Magdalena	0.14572	0.16117	−0.00466	0.04203	0.15193	0.15496	0.00193	0.03544
D16	Meta	0.11400	0.12711	0.28130	0.36048	0.11892	0.12219	0.31226	0.32952
D17	Nariño	0.11181	0.12708	−0.05509	0.14726	0.11424	0.12464	0.00651	0.08566
D18	Norte Santander	0.09992	0.10949	−0.15220	−0.09168	0.10378	0.10563	−0.13748	−0.10640
D19	Quindío	0.08089	0.09335	−0.19703	−0.10284	0.08606	0.08818	−0.18234	−0.11753
D20	Risaralda	0.09273	0.10176	−0.13238	0.77173	0.09707	0.09743	0.20565	0.43371
D21	Santander	0.18896	0.20755	−0.54192	−0.33773	0.19712	0.19939	−0.51375	−0.36591
D22	Sucre	0.07751	0.09137	0.20091	0.31687	0.08304	0.08584	0.19209	0.32568
D23	Tolima	0.09252	0.10932	−0.67090	0.54223	0.09921	0.10264	−0.07549	−0.05318
D24	Valle	0.11063	0.12433	0.31131	0.41675	0.11678	0.11818	0.33682	0.39124
D25	Amazonas	0.05964	0.06933	1.00127	1.63128	0.06380	0.06517	1.26571	1.36684
D26	Arauca	0.21969	0.32812	1.26506	1.61526	0.26288	0.28493	1.39586	1.48445
D27	Casanare	0.05409	0.06590	0.23381	0.28761	0.05865	0.06134	0.25952	0.26189
D28	Guanía	0.04981	0.05777	−11.80199	16.25231	0.05312	0.05446	1.83696	2.61336
D29	Guaviare	0.10619	0.12582	−3.12476	−2.39250	0.11438	0.11764	−2.76846	−2.74880
D30	Putumayo	0.08807	0.09549	−0.02026	0.12526	0.09045	0.09311	0.04432	0.06068
D31	San Andrés y Providencia	0.17729	0.18469	0.46830	0.60757	0.17999	0.18199	0.52974	0.54613
D32	Vaupés	0.03808	0.05204	−0.77122	−0.50942	0.04377	0.04634	−0.71516	−0.56548
D33	Vichada	0.15074	0.18322	−1.31811	−1.08386	0.16499	0.16897	−1.20236	−1.19960
	National	0.17054	0.18302	0.01558	0.03743	0.17411	0.17944	0.01925	0.03376

hypotheses on factor mobility and the role of price effects to better understand the consequences of trade opening in a developing economy. We found considerable differences from short-run and long-run impacts. While in the short-run structural constraints impose a spatial trap that leads to more concentration, in the long-run factor mobility enables spatial re-location of production in a way that regional disparities tend to diminish. In summary, long-run results using the spatial CGE approach has shown to be able to reconcile theoretical predictions based on recent economic geography models with empirical applications to real economies. However, this model (as with all CGE models) does not account for inertia factors that may preclude the spatial reallocations that the price signals indicate. As noted earlier, in Brazil, significant trade liberalization over a decade has not been accompanied by any significant spatial re-allocation of economic activity.

However, the model used and the analysis are not without their limitations. Although it is recognized that accurate parameters values are very important, it is not easy to find empirical estimates of key parameters, such as substitution elasticities in the literature. In the CEER model, calibration of some of the key parameters was based on limited information. Even though systematic sensitivity analysis was performed, other aspects of the model could be further tested, such as the degree of factor mobility, explored only partially in the two closures adopted, different sets of tariff reductions by sectors, and aspects involving alternative calibration. Moreover, CGE models provide results emanating from a given shock, from where one usually compares the changes in the variables of interest, but do not provide any insight on the dynamics to achieve these post-shock levels. One always wonders if transition was monotonic or if it has overshoot before setting in the final level. Perhaps a gradual relaxation of labour and capital mobility could shed some light on this.[19]

In this sense, directions for future research on this topic would include, among others, (*i*) accounting for the relative proportions of the quality of the labour force for better understanding the differential effects of trade liberalization; (*ii*) obtaining model-consistent econometric estimates for the key parameters; (*iii*) carrying out more realistic simulations considering differentiated sectoral specific tariff reductions in the realm of recent developments of Colombian trade policy (e.g. FTA with the USA); and (*iv*) examining different closure rules.

Appendix: The CGE core equations

The functional forms of the main groups of equations of the spatial CGE core are presented in this Appendix together with the definition of the main groups of variables, parameters and coefficients.

The notational convention uses uppercase letters to represent the levels of the variables and lowercase for their percentage-change representation. Superscripts (u), $u = 0, 1j, 2j, 3, 4, 5, 6$, refer, respectively, to output (0) and to the six different regional-specific users of the products identified in the model: producers in sector j ($1j$), investors in sector j ($2j$), households (3), purchasers of exports (4), regional governments (5) and the Central government (6); the second superscript identifies the domestic region where the user is located. Inputs are identified by two subscripts: the first takes the values $1, \ldots, g$, for commodities, $g + 1$, for primary factors, and $g + 2$, for 'other costs' (basically, taxes and subsidies on production); the second subscript identifies the source of the input, be it from domestic region b ($1b$) or imported (2), or coming from labour (1), capital (2) or land (3). The symbol (•) is employed to indicate a sum over an index.

[19] We are indebted to an anonymous referee for this point.

Equations

(A1) Substitution between products from different regional domestic sources

$$x_{(i(1b))}^{(u)r} = x_{(i(1\bullet))}^{(u)r} - \sigma_{(i)}^{(u)r}\Big(p_{(i(1b))}^{(u)r} - \sum_{l \in S^*}\big(V(i,1l,(u),r)\big/V(i,1\bullet,(u),r)\big(p_{(i(1l))}^{(u)r}\big)\Big)$$

$i = 1, \ldots, g$, $b = 1, \ldots, q$, $(u) = 3$ and (kj) for $k = 1$ and 2 and $j = 1, \ldots, h$, $r = 1, \ldots, R$

(A2) Substitution between domestic and imported products

$$x_{(is)}^{(u)r} = x_{(i\bullet)}^{(u)r} - \sigma_{(i)}^{(u)r}\Big(p_{(is)}^{(u)r} - \sum_{l=1\bullet,2}\big(V(i,l,(u),r)\big/V(i,\bullet,(u),r)\big(p_{(il)}^{(u)r}\big)\Big)$$

$i = 1, \ldots, g$, $s = 1\bullet$ and 2; $(u) = 3$ and (kj) for $k = 1$ e 2 and $j = 1, \ldots, h$, $r = 1, \ldots, R$

(A3) Substitution between labour, capital and land

$$\begin{aligned} x_{(g+1,s)}^{(1j)r} - a_{(g+1,s)}^{(1j)r} = \alpha_{(g+1,s)}^{(1j)r} x_{(g+1\bullet)}^{(1j)r} - \sigma_{(g+1)}^{(1j)r}\Bigg\{ & p_{(g+1,s)}^{(1j)r} + a_{(g+1,s)}^{(1j)r} \\ & - \sum_{l=1,2,3}\big(V(g+1,l,(1j),r)/V(g+1,\bullet,(1j),r)\big)\big(p_{(g+1,l)}^{(1j)r} + a_{(g+1,l)}^{(1j)r}\big)\Bigg\} \end{aligned}$$

$j = 1, \ldots, h$, $s = 1$, 2 and 3, $r = 1, \ldots, R$

(A4) Intermediate and investment demands for composites commodities and primary factors

$$x_{(i\bullet)}^{(u)r} = \mu_{(i\bullet)}^{(u)r} z^{(u)r} + a_{(i)}^{(u)r} \quad \begin{aligned} & u = (kj) \text{ for } k = 1,2 \text{ and } j = 1, \ldots, h \\ & \text{if } \ u = (1j) \ \text{ then } \ i = 1, \ldots, g+2 \\ & \text{if } \ u = (2j) \ \text{ then } \ i = 1, \ldots, g; \\ & r = 1, \ldots, R \end{aligned}$$

(A5) Household demands for composite commodities

$$V(i,\bullet,(3),r)\big(p_{(i\bullet)}^{(3)r} + x_{(i\bullet)}^{(3)r}\big) = \gamma_{(i)}^{r} P_{(i\bullet)}^{(3)r} Q^{r}\big(p_{(i\bullet)}^{(3)r} + x_{(i\bullet)}^{(3)r}\big) + \beta_{(i)}^{r}\left(C^{r} - \sum_{j \in G}\gamma_{(j)}^{r} P_{(i\bullet)}^{(3)r} Q^{r}\big(p_{(i\bullet)}^{(3)r} + x_{(i\bullet)}^{(3)r}\big)\right)$$

$i = 1, \ldots, g$, $r = 1, \ldots R$

(A6) Composition of output by industries

$$x_{(i1)}^{(0j)r} = z^{(1j)r} + \sigma^{(0j)r}\left(p_{(i1)}^{(0)r} - \sum_{t \in G}\big(Y(t,j,r)/Y(\bullet,j,r)\big)\, p_{(t1)}^{(0)r}\right)$$

$j = 1, \ldots, h$, i = 1, . . . , g, $r = 1, \ldots R$

(A7) Indirect tax rates

$$t(\tau,i,s,(u)r) = f_{(\tau)} + f_{(\tau i)} + f_{(\tau i)}^{(u)} + f_{(\tau i)}^{(u)r}, \quad \begin{aligned} & i = 1, \ldots, g; \quad s = 1b, 2 \text{ for } b = 1, \ldots, q; \ \tau = 1, \ldots, t \\ & (u) = (3),(4),(5),(6) \text{ and } (kj) \text{ for } k = 1,2; \ j = 1, \ldots, h \\ & r = 1, \ldots, R \end{aligned}$$

(A8) Purchasers' prices related to basic prices, margins (transportation costs) and taxes

$$V(i,s,(u),r)p_{(is)}^{(u)r} = \left(B(i,s,(u),r) + \sum_{\tau \in T} T(\tau,i,s,(u),r)\right)\left(p_{(is)}^{(0)} + t(\tau,i,s,u,r)\right)$$
$$+ \sum_{m \in G} M(m,i,s,(u),r)\,p_{(m1)}^{(0)r},$$
$$i = 1,\dots,g; (u) = (3),(4),(5),(6)$$
$$\text{and } (kj) \text{ for } k = 1,2 \text{ and } j = 1,\dots,h; s = 1b,2 \text{ for } b = 1,\dots,q$$
$$r = 1,\dots,R$$

(A9) Foreign demands (exports) for domestic goods

$$\left(x_{(is)}^{(4)r} - fq_{(is)}^{(4)r}\right) = \eta_{(is)}^{r}\left(p_{(is)}^{(4)r} - e - fp_{(is)}^{(4)r}\right), \quad i = 1,\dots,g; s = 1b,2 \text{ for } b = 1,\dots,q; r = 1,\dots,R$$

(A10) Regional government demands

$$x_{(is)}^{(5)r} = x_{(\bullet\bullet)}^{(3)r} + f_{(is)}^{(5)r} + f^{(5)r} + f^{(5)} \quad i = 1,\dots,g; s = 1b,2 \text{ for } b = 1,\dots,q; r = 1,\dots,R$$

(A11) Regional government demands

$$x_{(is)}^{(6)r} = x_{(\bullet\bullet)}^{(3)\bullet} + f_{(is)}^{(6)r} + f^{(6)r} + f^{(6)} \quad i = 1,\dots,g; s = 1b,2 \text{ for } b = 1,\dots,q; r = 1,\dots,R$$

(A12) Margins demands for domestic goods

$$x_{(m1)}^{(is)(u)r} = \theta_{(is)}^{(u)r} x_{(is)}^{(u)r} + a_{(m1)}^{(is)(u)r} \qquad \begin{array}{l} m,i = 1,\dots,g; \\ (u) = (3),(4b) \text{ for } b = 1,\dots,r, (5) \text{ and } (kj) \text{ for } k = 1,2; \\ j = 1,\dots,h; s = 1b,2 \text{ for } b = 1,\dots,r; \\ r = 1,\dots,R \end{array}$$

(A13) Demand equals supply for regional domestic commodities

$$\sum_{j \in H} Y(l,j,r)x_{(l1)}^{(0j)r} = \sum_{u \in U} B(l,1,(u),r)\,x_{(l1)}^{(u)r}$$
$$+ \sum_{i \in G}\sum_{s \in S}\sum_{u \in U} M(l,i,s,(u),r)\,x_{(l1)}^{(is)(u)r} \quad l = 1,\dots,g; r = 1,\dots,R$$

(A14) Regional industry revenue equals industry costs

$$\sum_{l \in G} Y(l,j,r)\left(p_{(l1)}^{(0)r} + a_{(l1)}^{(0)r}\right) = \sum_{l \in G^*}\sum_{s \in S} V(l,s,(1j),r)\left(p_{(ls)}^{(1j)r}\right), \quad j = 1,\dots,h; r = 1,\dots,R$$

(A15) Basic price of imported commodities

$$p_{(i(2))}^{(0)} = p_{(i(2))}^{(w)} - e + t_{(i(2))}^{(0)}, \quad i = 1,\dots,g$$

(A16) Cost of constructing units of capital for regional industries

$$V(\bullet,\bullet,(2j),r)\left(p_{(k)}^{(1j)r} - a_{(k)}^{(1j)r}\right) = \sum_{i \in G}\sum_{s \in S} V(i,s,(2j),r)\left(p_{(is)}^{(2j)r} + a_{(is)}^{(2j)r}\right), \quad j = 1,\dots,h; r = 1,\dots,R$$

(A17) Investment behaviour

$$z^{(2j)r} = x^{(1j)r}_{(g+1,2)} + 100 f^{(2j)r}_{(k)}, \quad j = 1, \ldots, h; r = 1, \ldots, R$$

(A18) Capital stock in period T + 1 − comparative statics

$$x^{(1j)r}_{(g+1,2)}(1) = x^{(1j)r}_{(g+1,2)} \quad j = 1, \ldots, h; r = 1, \ldots, R$$

(A19) Definition of rates of return to capital

$$r^r_{(j)} = Q^r_{(j)}\left(p^{(1j)r}_{(g+1,2)} - p^{(1j)r}_{(k)}\right), \quad j = 1, \ldots, h; r = 1, \ldots, R$$

(A20) Relation between capital growth and rates of return

$$r^r_{(j)} - \omega = \varepsilon^r_{(j)}\left(x^{(1j)r}_{(g+1,2)} - x^{(\bullet)r}_{(g+1,2)}\right) + f^r_{(k)}, \quad j = 1, \ldots, h; r = 1, \ldots, R$$

Other definitions in the CGE core include: revenue from indirect taxes, import volume of commodities, components of regional/national GDP, regional/national price indices, wage settings, definitions of factor prices, and employment aggregates.

Variables

Variable	Index ranges	Description
$x^{(u)r}_{(is)}$	$(u) = (3), (4), (5), (6)$ and (kj) for $k = 1, 2$ and $j = 1, \ldots, h$; if $(u) = (1j)$ then $i = 1, \ldots, g + 2$; if $(u) \neq (1j)$ then $i = 1, \ldots, g$; $s = 1b, 2$ for $b = 1, \ldots, q$; and $i = 1, \ldots, g$ and $s = 1, 2, 3$ for $i = g + 1$ $r = 1, \ldots, R$	Demand by user (u) in region r for good or primary factor (is)
$p^{(u)r}_{(is)}$	$(u) = (3), (4), (5), (6)$ and (kj) for $k = 1, 2$ and $j = 1, \ldots, h$; if $(u) = (1j)$ then $i = 1, \ldots, g + 2$; if $(u) \neq (1j)$ then $i = 1, \ldots, g$; $s = 1b, 2$ for $b = 1, \ldots, q$; and $i = 1, \ldots, g$ and $s = 1, 2, 3$ for $i = g + 1$ $r = 1, \ldots, R$	Price paid by user (u) in region r for good or primary factor (is)
$x^{(u)r}_{(i\bullet)}$	$(u) = (3)$ and (kj) for $k = 1, 2$ and $j = 1, \ldots, h$. if $(u) = (1j)$ then $i = 1, \ldots, g + 1$; if $(u) \neq (1j)$ then $i = 1, \ldots, g$ $r = 1, \ldots, R$	Demand for composite good or primary factor i by user (u) in region r
$a^{(1j)r}_{(g+1,s)}$	$j = 1, \ldots, h$ and $s = 1, 2, 3$ $r = 1, \ldots, R$	Primary factor saving technological change in region r
$a^{(u)r}_{(i)}$	$i = 1, \ldots, g$, $(u) = (3)$ and (kj) for $k = 1, 2$ and $j = 1, \ldots, h$ $r = 1, \ldots, R$	Technical change related to the use of good i by user (u) in region r
C^r		Total expenditure by regional household in region r
Q^r		Number of households
$z^{(u)r}$	$(u) = (kj)$ for $k = 1, 2$ and $j = 1, \ldots, h$ $r = 1, \ldots, R$	Activity levels: current production and investment by industry in region r
$fq^{(4)r}_{(is)}$	$i = 1, \ldots, g$; $s = 1b, 2$ for $b = 1, \ldots, q$ $r = 1, \ldots, R$	Shift (quantity) in foreign demand curves for regional exports
$fp^{(4)r}_{(is)}$	$i = 1, \ldots, g$; $s = 1b, 2$ for $b = 1, \ldots, q$ $r = 1, \ldots, R$	Shift (price) in foreign demand curves for regional exports

Variables Continued

Variable	Index ranges	Description
e		Exchange rate
$x_{(m1)}^{(is)(u)r}$	$m, i = 1, \ldots, g$; $s = 1b, 2$ for $b = 1, \ldots, q$ $(u) = (3), (4), (5), (6)$ and (kj) for $k = 1, 2$ and $j = 1, \ldots, h$ $r = 1, \ldots, R$	Demand for commodity $(m1)$ to be used as a margin to facilitate the flow of (is) to (u) in region r
$a_{(m1)}^{(is)(u)r}$	$m, i = 1, \ldots, g$; s = $1b, 2$ for $b = 1, \ldots, q$ $(u) = (3), (4), (5), (6)$ and (kj) for $k = 1, 2$ and $j = 1, \ldots, h$ $r = 1, \ldots, R$	Technical change related to the demand for commodity $(m1)$ to be used as a margin to facilitate the flow of (is) to (u) in region r
$x_{(i1)}^{(0j)r}$	$i = 1, \ldots, g$; $j = 1, \ldots, h$ $r = 1, \ldots, R$	Output of domestic good i by industry j
$p_{(is)}^{(0)r}$	$i = 1, \ldots, g$; $s = 1b, 2$ for $b = 1, \ldots, q$ $r = 1, \ldots, R$	Basic price of good i in region r from source s
$p_{(i(2))}^{(w)}$	$i = 1, \ldots, g$	USD c.i.f. price of imported commodity i
$t_{(i(2))}^{(0)}$	$i = 1, \ldots, g$	Power of the tariff on imports of i
$t\ (\tau, i, s, (u)\ r)$	$i = 1, \ldots, g$; $\tau = 1, \ldots, t$; $s = 1b, 2$ for $b = 1, \ldots, q$ $(u) = (3), (4), (5), (6)$ and (kj) for $k = 1, 2$ and $j = 1, \ldots, h$ $r = 1, \ldots, R$	Power of the tax τ on sales of commodity (is) to user (u) in region r
$f_{(k)}^{(2j)r}$	$j = 1, \ldots, h$ $r = 1, \ldots, R$	Regional-industry-specific capital shift terms
$f_{(k)}^{r}$	$r = 1, \ldots, R$	Capital shift term in region r
$x_{(g+1,2)}^{(1j)r}(1)$	$j = 1, \ldots, h$ $r = 1, \ldots, R$	Capital stock in industry j in region r at the end of the year, i.e., capital stock available for use in the next year
$p_{(k)}^{(1j)r}$	$j = 1, \ldots, h$ $r = 1, \ldots, R$	Cost of constructing a unit of capital for industry j in region r
$f_{(\tau)}$	$\tau = 1, \ldots, t$	Shift term allowing uniform percentage changes in the power of tax τ
$f_{(\tau i)}$	$\tau = 1, \ldots, t$; $i = 1, \ldots, g$	Shift term allowing uniform percentage changes in the power of tax τ on commodity i
$f_{(\tau i)}^{(u)}$	$\tau = 1, \ldots, t$; $(u) = (3), (4), (5), (6)$ and (kj) for $k = 1, 2$ and $j = 1, \ldots, h$	Shift term allowing uniform percentage changes in the power of tax τ of commodity i on user (u)
$f_{(\tau i)}^{(u)r}$	$\tau = 1, \ldots, t$; $(u) = (3), (4), (5), (6)$ and (kj) for $k = 1, 2$ and $j = 1, \ldots, h$ $r = 1, \ldots, R$	Shift term allowing uniform percentage changes in the power of tax τ of commodity i on user (u) in region r
$f_{(is)}^{(5)r}$	$i = 1, \ldots, g$; $s = 1b, 2$ for $b = 1, \ldots, q$ $r = 1, \ldots, R$	Commodity and source-specific shift term for regional government expenditures in region r
$f^{(5)r}$	$r = 1, \ldots, R$	Shift term for regional government expenditures in region r
$f^{(5)}$		Shift term for regional government expenditures
$f_{(is)}^{(6)r}$	$i = 1, \ldots, g$; $s = 1b, 2$ for $b = 1, \ldots, q$ $r = 1, \ldots, R$	Commodity and source-specific shift term for Central government expenditures in region r
$f^{(6)r}$	$r = 1, \ldots, R$	Shift term for Central government expenditures in region r
$f^{(6)}$		Shift term for Central government expenditures
ω		Overall rate of return on capital (short-run)
$r_{(j)}^{r}$	$j = 1, \ldots, h$ $r = 1, \ldots, R$	Regional-industry-specific rate of return

Parameters, Coefficients and Sets

Symbol	Description
$\sigma_{(i)}^{(u)r}$	Parameter: elasticity of substitution between alternative sources of commodity or factor i for user (u) in region r
$\sigma^{(0j)r}$	Parameter: elasticity of transformation between outputs of different commodities in industry j in region r
$\alpha_{(g+1,s)}^{(1j)r}$	Parameter: returns to scale to individual primary factors in industry j in region r
$\beta_{(i)}^{r}$	Parameter: marginal budget shares in linear expenditure system for commodity i in region r
$\gamma_{(i)}^{r}$	Parameter: subsistence parameter in linear expenditure system for commodity i in region r
$\varepsilon_{(j)}^{r}$	Parameter: sensitivity of capital growth to rates of return of industry j in region r
$\eta_{(is)}^{r}$	Parameter: foreign elasticity of demand for commodity i from region r
$\theta_{(is)}^{(u)r}$	Parameter: scale economies to transportation of commodity (i) produced in region r shipped to user (u) in region r
$\mu_{(i\bullet)}^{(u)r}$	Parameter: returns to scale to primary factors ($i = g + 1$ and $u = 1j$); otherwise, $\mu_{(i\bullet)}^{(u)r} = 1$
$B\ (i, s, (u), r)$	Input-output flow: basic value of (is) used by (u) in region r
$M\ (m, i, s, (u), r)$	Input-output flow: basic value of domestic good m used as a margin to facilitate the flow of (is) to (u) in region r
$T\ (\tau, i, s, (u), r)$	Input-output flow: collection of tax τ on the sale of (is) to (u) in region r
$V\ (i, s, (u), r)$	Input-output flow: purchasers' value of good or factor i from source s used by user (u) in region r
$Y\ (i, j, r)$	Input-output flow: basic value of output of domestic good i by industry j from region r
$Q_{(j)}^{r}$	Coefficient: ratio, gross to net rate of return
G	Set: $\{1,2, \ldots, g\}$, g is the number of composite goods
G*	Set: $\{1,2, \ldots, g + 1\}$, $g + 1$ is the number of composite goods and primary factors
H	Set: $\{1,2, \ldots, h\}$, h is the number of industries
U	Set: $\{(3), (4), (5), (6), (k\,j)$ for $k = 1, 2$ and $j = 1, \ldots, h\}$
U*	Set: $\{(3), (k\,j)$ for $k = 1, 2$ and $j = 1, \ldots, h\}$
S	Set: $\{1, 2, \ldots, r + 1\}$, $r + 1$ is the number of regions (including foreign)
S*	Set: $\{1, 2, \ldots, r\}$, r is the number of domestic regions
T	Set: $\{1, \ldots, t\}$, t is the number of indirect taxes

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