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**A MACROECONOMIC
ASSESSMENT OF THE CLEAN
DEVELOPMENT MECHANISM
(CDM) IN PERU: A CGE ANALYSIS**

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A macroeconomic assessment of the Clean Development Mechanism (CDM) in Peru: A CGE analysis

Jean-Marc Montaud · Nicolas Pécastaing

Abstract:

The Clean Development Mechanism (CDM) under the Kyoto Protocol constitutes a major tool in the fight against climate change; it also is an important foreign direct investment funding opportunity for southern countries. Yet few studies have focused on the economic impact of CDM on host countries. This study attempts such an assessment in Peru, using a computable general equilibrium model that accounts for both the productive and regional dualism of the national economy. The numerical simulation of macroeconomic shocks generated by current and future CDM investments reveals the significant potential impact of such projects in terms of employment, growth, and regional imbalance in this developing country.

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1 Introduction

The international community confronts significant challenges associated with encouraging southern countries to participate in the fight against climate change without hindering their development. The Clean Development Mechanism (CDM) under the Kyoto Protocol is one example of this dual development–environmental issue. This mechanism allows northern countries¹ to make foreign direct investment (FDI) at the lowest cost in southern countries,² through carbon credit granted in proportion to the greenhouse gas reductions achieved. Host countries benefit from environmentally friendly technology transfers and additional funding sources for their development.

Since the first CDM project was registered in November 2004, CDM investments have enjoyed great success, increasing to 3,395 projects in 2011: 81.1% in Asia, 14.1% in Latin America and the Caribbean, and 2.65% in Africa (Fenhann 2011). However, their influence in terms of development is an insufficiently explored research area. Most approaches are focused on the project's environmental objective, and the few assessments of their contribution to development tend to be partial, heterogeneous, and based on controversial qualitative approaches.

Our objective is to contribute a quantitative assessment of the macroeconomic impact of CDM investments on a developing economy, using the specific case of Peru. This country is particularly sensitive to environmental issues, considering its vulnerability to climate change, and it ratified the Kyoto Protocol in September 2002. Since 2005, CDM Peruvian projects have increased rapidly and broadly, representing a real investment opportunity for this developing country. In 2009, Peru was among the 10 most attractive countries for CDM investments (Point Carbon 2009).

This analysis is based on a computable general equilibrium (CGE) model that considers an essential characteristic of Peruvian underdevelopment, namely, its dualism. In the next section, we address the limits of the CDM assessment in terms of development. Then we explicate the CGE model and its database. Finally, we address the main results of the macroeconomic impact simulations of current and future CDM projects in Peru.

2 CDM contributions to development

In economic literature, CDM assessment analyses focus mainly on their capacity to reduce greenhouse gas emissions rather than on its development objective (Austin and Faeth 2000; Olsen 2007). The first explanation refers to the strong incentives to assess the environmental impact, especially because such assessments determine the level of revenues generated by each project with regard to the carbon market. On the other hand, the contribution to development is just one objective mentioned in the *project design document*³ (PDD), designed to facilitate acceptance by the *designed national authority* (DNA) of the host country.

Since the signature of the Kyoto Protocol though, few analyses have managed to assess the potential impact of CDM on southern countries' development. Some studies adopt quantitative approaches (Banuri and Gupta 2000; Mathy et al. 2001), though the majority engage in qualitative

¹ These “Annex I” countries are subject to mandatory quantified emission reduction objectives.

² These “non-Annex I” countries receive CDM projects. They must have adopted the Kyoto Protocol and appointed a *designed national authority* (DNA), which is responsible for validating each project.

³ Each CDM project requires a PDD. It gives information on the project's legislative aspects, its implementation, its baseline scenarios adopted, its funding sources and the local operators concerned. It should also describe its potential impact in terms of infrastructure, jobs, social project funding or environmental quality improvement.

analyses. But multicriteria evaluations suggest heterogeneous assessments, distinguished by the choice and respective weight of development criteria, as well as the nature or location of the project (Anagnostopoulos et al. 2004; Begg et al. 2003; Huq 2002; Kolshus et al. 2001; Olhoff et al. 2004; Sutter 2003). In such a context, many authors emphasize the need to apply an international standard to rate CDM projects, in accordance with their contribution to the various dimensions of sustainable development (Cosbey 2006; Cosbey et al. 2005; Schlup 2005; Sutter and Parreño 2007).⁴ Although these standardization efforts have contributed to clarifying the debate and homogenizing extant analyses, they do not address all the concerns linked to assessments of a CDM's development objective. In particular, their relevance is limited due to the arbitrary weight assigned to different indicators. The information pertaining to development listed in the PDDs also remains often incomplete and subject to discussion, at both quantitative and qualitative levels (Alexeew et al. 2010). Finally, the role played by national DNAs with regard to the selection of projects may bias assessments. Performed without ex post verification by independent studies (Subbarao and Lloyd 2011), this choice usually reflects national priorities and specific concepts of development (Boyd et al. 2009; Bumpus and Cole 2010) or even is guided by the competitive pressure of other DNAs that also try to attract CDM investments.⁵

In this context and despite these difficulties, we attempt an economic assessment of CDM impact in a developing country such as Peru. We work in turn to fit both quantitative and developmental approaches by modeling the ex post macroeconomic impact of CDM investment flows in this economy.

3 Multisectoral and multiregional CGE model of Peru

The model is based on a CGE framework. This kind of analysis has gradually imposed in development economics from the 80s (Dervis et al. 1982; Robinson 1989). Because it gives emphasis on global interactions among supply, income, and demand through market mechanisms, it allows simulating macroeconomic reactions of the economy in front of various external shocks. Here, CDM investments may be one of these shocks. On the other hand, it allows a wide range of choice of agents or productive structures in order to take into account the structural characteristics of the studied economy. In this spirit, we choose here to focus on a key characteristic of Peruvian underdevelopment: its dual-dual nature.⁶ The model equations appear in Appendix.

3.1. Peru: a dual–dual economy

As Lewis (1954) established long ago, *dualism* is a primary symptom of underdevelopment. In Peru, this dual character is doubly prominent. First, we find an urban productive dichotomy between formal and informal sectors. This informal sector consists of small non-capitalistic microenterprises that operate outside the institutional framework or modern production standards. It relates to the formal sector through the labor market, in that it serves as a shelter segment for workers excluded from formal employment and unprotected by an efficient social insurance system. In 2011, the Peruvian informal sector constituted 10.1% of the GDP and almost 50% of employment (MTPE 2004). Second,

⁴ Olsen and Fenhann (2008) show for example that the potential benefits of 744 CDM projects may be regrouped in five main principles: job creation, economic growth, air quality, access to energy and well-being of the people.

⁵ Brown et al. (2004) emphasize the need for strong and independent local institutions to analyze the socio-environmental consequences of the CDMs.

⁶ For an analysis of a dual-dual economy in a CGE framework see Thorbecke (1997)

dualism stems from the geographic imbalance across Peru's three regions: Costa, Sierra, and Selva. In 2011, Costa accounted for 54% of national employment (33% for Selva, 13% for Sierra) and 70% of the national GDP (25% for Selva, 5% for Sierra) (see INEI 2011a, b). This regional disparity historically has been explained by the demographic, administrative, and commercial importance of Lima and its strong contributions to the development of Costa.⁷ In recent years, the disparity has been particularly reinforced, because dynamic sectors (transport, construction, industries) have been mostly developed in Costa, whereas declining sectors (agriculture and mining) are located inland.

3.2 Model structure

The CGE model divides the national Peruvian economy into two regions: Costa and inland.⁸ Each works as a whole economy, with its own agents and production sectors, linked through interregional commercial trade and, at the macroeconomic level, through a common balance of payments, a central public administration, a common job market, and a national capital market that ensures a savings–investment balance.⁹ Each region hosts two groups of activities (formal and informal), two types of households (rural and urban), and two levels of labor qualifications (skilled and unskilled).

On the supply side, formal activities maximize profit by combining fixed capital with skilled and unskilled labor (see Eq. 1–4). Their products may be sold locally, to the rest of the world, or to other regions (Eq. 6–9); they are imperfectly substitutable with imported products (Eq. 10–13). Informal products can be obtained only from unskilled labor with a low fixed physical productivity (Eq. 5). They are only sold in regional markets for final household consumption.

On the demand side, urban and rural households perceive income from their initial endowments as input factors and their respective access to central Peruvian State transfer incomes (Eq. 14–20). Their consumption of formal products should be a Linear Expenditure System function (Eq. 22–23). Their consumption of informal products is residual and allocated, according to budget coefficients assumed to be fixed in the short term (Eq. 24).

Regional price variations ensure the market balance of goods and services in each region (Eq. 37–38). The labor market closure is based upon a labor interregional mobility hypothesis. Skilled labor supply should be fixed in volume at the national level, and the real wage variations ensure the market balance (Eq. 41). A skilled wage differential between regions instead may be introduced to consider the differences in standards of living between the Costa region and the rest of the country (Eq. 42). For the non-skilled labor segment, supply is fixed at the national level (Eq. 43), and real wages should be rigid to increases. The market balance exists due to informal employment volumes. In each region, a worker who is not employed in formal urban activities creates an individual informal microenterprise. Inland, these workers have the additional option of migrating toward Costa, which occurs according to a Harris-Todaro specification, that is, by comparing the average earnings obtained through an inland informal sector and the probable gains expected in Costa (Eq. 44). At the end of the migration process, labor surplus distribution among informal activities reflects an exogenous key, calibrated from the base year database (Eq. 45).¹⁰ In each region, informal trade activity receives particular treatment, because the volume of demand is determined by the volume of economic activity. Its labor productivity parameter thus plays a role as an adjustment variable (Eq. 40) (also see Kelley 1994).

⁷ Lima hosts 30.8% of the Peruvian population and centralizes its main administrations. Its proximity to Callao Harbor also makes it an essential location in foreign trade.

⁸ Combining the Selva and Sierra regions into a single, inland also reflects data availability, and particularly the existence of two regional social accounting matrices (Nin-Pratt et al. 2011).

⁹ For a similar approach to Peru, see Nin-Pratt et al. (2009).

¹⁰ These keys may be interpreted as indicators of barriers to entry for each informal branch.

Foreign account closures and saving–investment balances refer to the national level (Eq. 48–49). CDM investments are taken into account at this level and considered as FDI that may be regionally and sectorally allocated across formal activities. Their impact on the Peruvian economy thus can be understood only in terms of demand shocks.¹¹

3.3 Model database

The parametrical calibration of the model stems from two regional social accounting matrices (SAM), for Costa and inland (Nin-Pratt et al. 2011). For the purposes of our analysis, we reduced the number of formal activities to 17, while we also introduced 6 informal activities. This addition is possible because we use data from Peruvian employment surveys (MTPE 2004) and secondary sources (Loayza 2007; Robles 2003; Rodriguez and Higa 2010), which support an estimation of informal activities' contributions to employment and the GDP of each region. A restricted definition of informal employment, corresponding to individual entrepreneurs—with the main hypothesis that, in the absence of taxes or social charges, microentrepreneurs receive the full value added they generate—suggests that, at initial equilibrium, the informal sector represents 10.1% of the Peruvian GDP and 52.8% of total employment, with 30% of informal production found inland and 70% in Costa.¹²

4 Simulations and results

4.1 Baseline scenarios of CDM impact on the Peruvian economy

The data pertaining to the type, location, amount, and stage of completion of CDM investments in Peru come from the CDM pipeline (Fenhann 2012), supplemented by data from the UNFCCC¹³ to detail each PDD and from FONAM (2010, 2011).¹⁴ We thus can identify three successive waves of CDM projects: 26 “registered” projects already validated by the CDM executive board, 31 projects still “at validation,” and 90 pending projects, described only in the Peruvian DNA's portfolio. Each project analysis enables the identification of their impact in terms of demand on other economic activities and on the pertinent region. We summarize these data in Table 1. They constitute the reference framework for our numerical simulations.

The first simulation, which is the most restricted one, considers the impact of the 26 “registered” projects (i.e., US\$1079.3 million). The second one denotes the effect of the 31 CDM projects currently “at validation” (US\$2411.4 million). Finally, a last simulation offers a prospective scenario of the potential impact of the 90 pending projects (US\$8709.4 million).

¹¹ An analysis in terms of supply would imply a structural modification of the model's parameters and particularly of the Peruvian energy matrix. However, considering the diversity of CDM projects, their different temporary horizons, and the absence of reliable data about their impact on intermediate energy consumers, we chose not to consider this supply effect.

¹² To avoid upsetting the initial coherence of each regional SAM, we deducted the added value estimated of informal activities from the value of corresponding formal activities, as estimated in official national accounts.

¹³ United Nations Framework Convention on Climate Change. [Available online from <http://cdm.unfccc.int>].

¹⁴ In Peru, the MINAM (*Ministerio del Ambiente*) evaluates the quality of projects, whereas the FONAM's (*Fondo Nacional del Ambiente*) mission is to promote CDM.

Table 1 Regional and sectoral distribution of CDM investments to Peru by achievement stage (US\$ millions)

	<i>Registered</i>	<i>At Validation</i>	<i>Portfolio</i>
Region			
<i>Costa</i>	856,5	1784,9	6128,0
<i>Inland</i>	222,8	1705,8	6072,1
<i>Total national</i>	1079,3	3490,7	12200,1
Activities			
<i>Machinery and equipment (act.9)</i>			
<i>Costa</i>	231,3	481,9	1654,6
<i>Inland</i>	60,1	460,6	1639,5
<i>Total national</i>	291,4	942,5	3294,0
<i>Construction (act.10)</i>			
<i>Costa</i>	453,9	946,0	3247,8
<i>Inland</i>	118,1	904,1	3218,2
<i>Total national</i>	572,0	1850,1	6466,1
<i>Transport and communication (act.14)</i>			
<i>Costa</i>	68,5	142,8	490,2
<i>Inland</i>	17,8	136,5	485,8
<i>Total national</i>	86,3	279,3	976,0
<i>Business services (act.15)</i>			
<i>Costa</i>	68,5	142,8	490,2
<i>Inland</i>	17,8	136,5	485,8
<i>Total national</i>	86,3	279,3	976,0
<i>Other private services (act.16)</i>			
<i>Costa</i>	34,3	71,4	245,1
<i>Inland</i>	8,9	68,2	242,9
<i>Total national</i>	43,2	139,6	488,0

4.2 Results

Simulations are conducted according to a cumulative dynamic logic. The general equilibrium obtained after simulation 1 serves as initial reference equilibrium for simulation 2, which then does so for simulation 3. The results appear in Tables 2 and 3.

In the first simulation, the demand shock generated by the CDM investments accounts for 1.8% of the formal GDP, largely concentrated in the Costa region, which captures 79.4% of new investments. The results also reveal the globally positive impact of this shock at the national level, in the form of GDP growth of 0.37%. It increases inflation in both formal (+1.94%) and informal (+0.70%) sectors. The global increase of incomes for skilled and unskilled labor primarily benefits rural households. Urban households instead are more affected by reductions in informal employment, so they see their incomes decrease. The portion of public deficit in the GDP decreases (-4.36%) due to the effects of revenue and activity growth. The national volume of imports and exports also increases, improving the trade balance. This first simulation reveals an emphasis of Peruvian regional dualism in favor of the Costa region, whose dominance in terms of production, revenues, and employment increases. Its GDP grows 0.97%, whereas that of the inland region decreases by -1.22%. Inflation also is stronger in Costa (+2.12%) than inland (+1.53%), and the proportion of exports from this region, which grow relatively less competitive, also decreases. Therefore, productive dualism declines, and the informal sector effectively plays its role as a labor reservoir at the national level. The volume of informal employment decreases in both regions. Taking into account the compensation differentials between regions and labor migration movements, we recognize that this reallocation of resources basically moves in favor of unskilled formal employment in Costa (+2.09%), while unskilled formal employment inland slightly decreases (-0.62%).

The second simulation reveals an even more intense demand shock caused by the CDMs (about 5.9% of the formal GDP) and initiates a process of regional rebalancing because the inland region receives close to 49% of investments. These results reinforce the previous scenario: The impact of CDM investments is globally positive for the national economy. Supply, employment, and incomes increase, though the price effects grow stronger in both the formal and the informal sectors at this point. Regional imbalance tends to diminish in terms of non-skilled employment and production, as well as sectoral dualism, though the price effects ultimately mean an increase of the informal GDP as a proportion of the national economy.

Considering the importance of the demand shock envisaged in the third simulation, we note much more important price effects than in the previous two simulations (+12.49% in the informal sector, +13.79% in the formal sector, national level). These effects contribute to a general increase of income and GDP in both economic spheres. Productive dualism continues to decrease in volume, with a strong decrease of informal employment in favor of unskilled formal employment. Finally, the informal sector accounts for only 33.72% of total employment compared with 40.08% at the beginning. This evolution is particularly sensitive in the Costa region, whose part decreases by close to 10% (cf. 3% in the inland region). The contribution of the informal sector to total GDP increases, considering the pressure on prices. Finally, we note a catch-up effect inland in terms of employment, though it appears insufficient to threaten the hegemony of the Costa region.

Table 2 CDM investment effects on Peruvian economic variables (variation)

	COAST			INLAND			NATIONAL		
	SC1/SC0	SC2/SC1	SC3/SC2	SC1/SC0	SC2/SC1	SC3/SC2	SC1/SC0	SC2/SC1	SC3/SC2
<i>CDM investment</i>	10.65	20.06	57.36	4.51	32.79	88.55	8.32	24.73	69.56
INFORMAL SECTOR									
<i>Employment</i>	-0.10	-5.26	-21.52	-1.25	-3.12	-0.70	-0.65	-4.25	-11.57
<i>GDP (value)</i>	0.48	5.38	41.71	-0.63	1.55	24.72	0.15	4.24	36.78
<i>Commission rate</i>	5.53	11.23	80.58	8.35	4.82	25.60	0.80	8.86	54.67
<i>Informal price index</i>	0.98	8.33	12.49	0.04	7.20	12.98	0.70	7.99	12.59
FORMAL SECTOR									
<i>Skilled employment</i>	0.88	1.34	-4.41	-2.36	-3.71	12.85	0.00	0.00	0.00
<i>Unskilled employment</i>	2.09	2.93	12.65	-0.62	3.72	5.50	0.52	3.38	8.53
<i>GDP (value)</i>	1.02	4.09	8.44	-1.28	0.32	2.87	0.37	3.03	6.92
<i>Skilled labor income</i>	0.78	21.06	-2.31	-2.46	15.04	15.32	0.17	19.95	0.80
<i>Unskilled labor income</i>	2.09	2.93	12.65	-0.62	3.72	5.50	1.31	3.16	10.61
<i>Capital income</i>	0.60	0.81	9.37	-1.43	-2.90	-0.09	-0.01	-0.29	6.64
<i>Income urban households</i>	1.22	1.92	10.84	-1.15	-0.81	2.48	-0.59	-0.15	4.55
<i>Income rural households</i>	1.24	5.56	8.39	-1.15	2.49	6.78	0.69	4.87	8.04
<i>Formal price index</i>	2.12	7.14	13.79	1.53	12.96	41.53	1.94	8.88	21.81
MACRO									
<i>GDP</i>	0.97	4.21	11.73	-1.22	0.45	5.2	0.34	3.15	9.94
<i>Part of public deficit/GDP (%)</i>							1.02%	0.97%	1.89%
<i>Public savings</i>	-3.71	40.63	-29.81	-3.08	-15.67	0.10	-4.36	99.76	-43.07
<i>Foreign savings</i>							161.2	172.9	173.5

Sources: Numerical model simulations, using GAMS software.

Table 3 CDM investment effects on the dualism of Peruvian economy

Productive dualism: Evolution of the informal sector (%) in the national economy												
	NATIONAL				COAST				INLAND			
	Initial	SC1	SC2	SC3	Initial	SC1	SC2	SC3	Initial	SC1	SC2	SC3
<i>Employment</i>	40.08	39.83	38.13	33.72	42.66	42.21	40.29	32.85	37.58	37.47	36.02	34.52
<i>Unskilled employment</i>	44.62	44.33	42.45	37.54	50.20	49.66	47.58	38.74	39.74	39.59	37.97	36.56
<i>GDP</i>	10.00	9.98	10.09	12.55	9.81	9.76	9.87	12.52	10.49	10.55	10.67	12.64
<i>Income urban households</i>	11.50	11.47	11.50	14.19	11.91	11.83	11.84	14.91	10.65	10.70	10.75	12.51
Regional dualism: Evolution of each region (%) in the national economy												
	COAST/NATIONAL				INLAND/NATIONAL							
	Initial	SC1	SC2	SC3	Initial	SC1	SC2	SC3				
<i>Imports</i>	80.66	80.57	69.24	57.27	19.34	19.43	30.76	42.73				
<i>Exports</i>	58.13	53.59	51.12	52.26	41.87	46.41	48.88	47.74				
<i>Skilled employment</i>	72.83	73.47	74.46	71.17	27.17	26.53	25.54	28.83				
<i>Unskilled employment</i>	46.63	47.10	46.56	44.88	53.37	52.90	53.44	55.12				
<i>GDP</i>	71.36	71.80	72.54	73.72	28.64	28.20	27.46	26.28				
<i>Skilled labor income</i>	81.09	81.59	82.34	79.80	18.91	18.41	17.66	20.20				
<i>Unskilled labor income</i>	70.74	71.20	71.32	73.03	29.26	28.80	28.68	26.97				
<i>Capital income</i>	69.87	70.29	71.07	72.89	30.13	29.71	28.93	27.11				
<i>Income rural households</i>	23.80	24.23	24.74	26.22	76.20	75.77	75.26	73.78				
<i>Income urban households</i>	76.10	76.50	77.05	77.48	23.90	23.50	22.95	22.52				

Sources: Numerical model simulations, using GAMS software.

5 Conclusion

Faced with a lack of analysis in extant economic literature, this study proposes a macroeconomic assessment of the impacts of CDM investments on the Peruvian economy, which is characterized by both productive and regional dualism. The numerical simulations obtained with a CGE model capture the endemic features of Peruvian underdevelopment and effectively reveal the globally positive impact of the CDM investments and their demand shock on national growth, as well as on the reduction of productive dualism. Even if the regional unbalance may be reinforced at the first step of CDM process, it tends to diminish as the projects gradually reach completion.

Despite these interesting initial results, there is room to improve our approach. For example, an effective research extension would include the environmental dimension of the CDM impact, together with the macroeconomic dimension. Unfortunately, the current condition of Peruvian environmental accounting does not support such a joint analysis yet. Similarly, the integration of the effects of the technological transfer linked to the CDM in the production function of agents also could enrich our analysis, by allowing for the consideration of the supply effects that result from these investments.

APPENDIX: Peruvian CGE Model

1. Index and Sets

Regions – $r \in R = \{Costa, Inland\}$

Households – $h \in H = \{Urb: Urban households, Rur: Rural households\}$

Activities or commodities – $a \in A = \{Act1: Agriculture and Forestry; Act2: Fisheries; Act3: Mining and oil; Act4: Food processing; Act5: Textiles and Clothing; Act6: Wood products; Act7: Paper products and Publishing industries; Act8: Chemicals, Pharmaceutical industries and Refined petroleum; Act9: Non-metallic minerals, Metals, Machinery and equipment; Act10: Construction; Act11: Water and electricity; Act12: Retail and wholesale trade; Act13: Hotels and catering; Act14: Transport and communication; Act15: Business services; Act16: Other private services; Act17: Government services; Act18: Informal manufacturing; Act19: Informal Construction; Act20: Informal Trade; Act21: Informal Restaurants; Act22: Informal Transport; Act23: Other informal services \}$

Formal activities - for (or i) $\in FOR \subset A / FOR = \{Act1, ..., Act17\}$
Formal trade services - Comf $\in FOR / Comf = \{act12\}$

Informal activities - nf (or j) $\in NF \subset A / NF = \{Act18, ..., Act23\}$
Informal trade services- Comnf $\in NF = \{act20\}$

2. Equations

Regional Production Block

Formal production process

$$\begin{aligned} 1. \quad QX_{for}^r &= AX_{for}^r \left[\delta x_{for}^r \cdot LD_{for}^r \cdot \mu_{for}^r + (1 - \delta x_{for}^r) \bar{K}_{for}^r \right]^{-\frac{1}{\mu_{for}^r}} \\ 2. \quad LD_{for}^r &= QX_{for}^r \left[\frac{\delta x_{for}^r \cdot PVA_{for}^r}{(AX_{for}^r)^{\mu_{for}^r} \cdot w_{for}^r} \right]^{\alpha_{for}^r} \\ 3. \quad LD_{for}^r &= AI_{for}^r \left[\delta l_{for}^r \cdot LDS_{for}^r \cdot \mu_{for}^r + (1 - \delta l_{for}^r) LDNS_{for}^r \cdot \mu_{for}^r \right]^{-\frac{1}{\mu_{for}^r}} \\ 4. \quad \frac{LDS_{for}^r}{LDNS_{for}^r} &= \left[\frac{\bar{w}_{ns}}{w_s} \cdot \frac{\delta l_{for}^r}{1 - \delta l_{for}^r} \right]^{\alpha_{for}^r} \end{aligned}$$

Informal production process

$$5. \quad QD_{nf}^r = \gamma_{nf} \cdot LDNS_{nf}^r$$

Output transformation for locally sold and non-locally sold formal products

$$\begin{aligned} 6. \quad QX_{for}^r &= AI_{for}^r \left[\delta l_{for}^r \cdot QE_{for}^r \cdot \mu_{for}^r + (1 - \delta l_{for}^r) QD_{for}^r \cdot \mu_{for}^r \right]^{-\frac{1}{\mu_{for}^r}} \\ 7. \quad \frac{QE_{for}^r}{QD_{for}^r} &= \left[\frac{\delta l_{for}^r}{1 - \delta l_{for}^r} \cdot \frac{PE_{for}^r}{PD_{for}^r} \right]^{\alpha_{for}^r} \end{aligned}$$

Export transformation for interregional and international formal markets

$$\begin{aligned} 8. \quad QE_{for}^r &= Ae_{for}^r \left[\delta e_{for}^r \cdot QER_{for}^r \cdot \mu_{for}^r + (1 - \delta e_{for}^r) QEW_{for}^r \cdot \mu_{for}^r \right]^{-\frac{1}{\mu_{for}^r}} \\ 9. \quad \frac{QER_{for}^r}{QEW_{for}^r} &= \left[\frac{\delta e_{for}^r}{1 - \delta e_{for}^r} \cdot \frac{PER_{for}^r}{ER \cdot PEW_{for}^r} \right]^{\alpha_{for}^r} \end{aligned}$$

Substitution between local and non-local formal products

$$\begin{aligned} 10. \quad QQ_{for}^r &= Aq_{for}^r \left[\delta q_{for}^r \cdot QM_{for}^r \cdot \mu_{for}^r + (1 - \delta q_{for}^r) QD_{for}^r \cdot \mu_{for}^r \right]^{-\frac{1}{\mu_{for}^r}} \\ 11. \quad \frac{QM_{for}^r}{QD_{for}^r} &= \left[\frac{(PD_{for}^r + icd_{for}^r \cdot PQ_{comf}^r)}{PM_{for}^r} \cdot \frac{\delta q_{for}^r}{1 - \delta q_{for}^r} \right]^{\alpha_{q_{for}^r}} \end{aligned}$$

Substitution between interregional and international formal products

$$\begin{aligned} 12. \quad QM_{for}^r &= Am_{for}^r \left[\delta m_{for}^r \cdot QMR_{for}^r \cdot \mu_{for}^r + (1 - \delta m_{for}^r) QMW_{for}^r \cdot \mu_{for}^r \right]^{-\frac{1}{\mu_{for}^r}} \\ 13. \quad \frac{QMR_{for}^r}{QMW_{for}^r} &= \left[\frac{PMW_{for}^r}{PMR_{for}^r} \cdot \frac{\delta m_{for}^r}{1 - \delta m_{for}^r} \right]^{\alpha_{m_{for}^r}} \end{aligned}$$

Regional Income, Demand and Savings Block

Formal incomes

$$\begin{aligned} 14. \quad YK^r &= \sum_{for} (PVA_{for}^r \cdot QA_{for}^r - w_{for}^r \cdot LD_{for}^r) \\ 15. \quad YSL^r &= \sum_{for} w_s \cdot LDS_{for}^r \\ 16. \quad YNSL^r &= \sum_{for} \bar{w}_{ns} \cdot LDNS_{for}^r \end{aligned}$$

Informal incomes

$$\begin{aligned} 17. \quad YINF^r &= \sum_{nf} PVA_{nf}^r \cdot QD_{nf}^r \\ 18. \quad inc_{nf}^r &= \frac{YINF^r}{\sum_{nf} LDNS_{nf}^r} \end{aligned}$$

Regional institutions incomes

$$\begin{aligned} 19. \quad Y_{rur}^r &= \phi_{rur}^r YSL^r + \phi_{ns_{rur}}^r YNSL^r + \phi_{kr_{rur}}^r YK^r + Pindex.Transf_{rur}^r \\ 20. \quad Y_{urb}^r &= \phi_{urb}^r YSL^r + \phi_{ns_{urb}}^r YNSL^r + \phi_{kr_{urb}}^r YK^r + Pindex.Transf_{urb}^r + YINF^r \end{aligned}$$

$$21. Y_G = \sum_r \sum_h ty_h^r Y_h^r + \sum_r tk^r YK^r + \sum_r \sum_{for} tm_{for}^r ER.PWM_{for}^r.QMW_{for}^r + \sum_r \sum_{for} tq_{for}^r PQ_{for}^r.QQ_{for}^r$$

Regional household's consumption demand

$$22. PQ_{for}^r.CQH_{h,for}^r = c \min_{h,for}^r PQ_{for}^r + pmc_{h,for}^r \left[EH_h^r - \sum_{for} c \min_{h,for}^r PQ_{for}^r \right]$$

$$23. EH_h^r = (1 - ty_h^r - pmc_{h,nf}^r) Y_h^r - S_h^r$$

$$24. PD_{nf}^r.CQH_{h,nf}^r = pmc_{h,nf}^r Y_h^r$$

Savings

$$25. S_h^r = mps_h^r (1 - ty_h^r) Y_h^r$$

$$26. S_G = Y_G - \sum_r \sum_{for} PQ_{for}^r.CQG_{for}^r - Pindex \cdot \sum_r \sum_h Transf_h^r$$

$$27. S_K^r = (1 - tk^r - \sum_h \phi_k^r) YK^r$$

Regional Price System Block

$$28. PX_{for}^r = PVA_{for}^r + \sum_i ica_{i,for}^r PQ_i^r$$

$$29. PD_{nf}^r = PVA_{nf}^r + \sum_{for} ica_{for,nf}^r PQ_{for}^r$$

$$30. w_{for}^r.LD_{for}^r = w_{ns}^r.LDNS_{for}^r + w_s^r.LDS_{for}^r$$

$$31. PX_{for}^r.QX_{for}^r = PD_{for}^r.QD_{for}^r + PE_{for}^r.QE_{for}^r$$

$$32. PE_{for}^r.QE_{for}^r = PER_{for}^r.QER_{for}^r + ER.PEW_{for}^r.QEW_{for}^r$$

$$33. PQ_{for}^r (1 - tq_{for}^r).QQ_{for}^r = (PD_{for}^r + ica_{for,for}^r.PQ_{comf}^r) QD_{for}^r + PM_{for}^r.QM_{for}^r$$

$$34. PM_{for}^r.QM_{for}^r = PMW_{for}^r.QMW_{for}^r + PMR_{for}^r.QMR_{for}^r$$

$$35. PMW_{for}^r = ER.PWM_{for}^r + ica_{for,for}^r.PQ_{comf}^r + tm_{for}^r$$

$$36. PMR_{for}^r = PER_{for}^r + ica_{for,nf}^r.PQ_{comf}^r$$

Closure Rules Block

Regional commodity markets

$$37. QQ_{for}^r = \sum_h CQH_{h,for}^r + CQG_{for}^r + \sum_{for'} ica_{for,for'}^r.QX_{for'}^r + \sum_{inf} ica_{for,inf}^r.QD_{inf}^r + QINVP_{for}^r$$

$$38. QD_{nf}^r = \sum_h CQH_{h,nf}^r$$

$$39. QQ_{comf}^r = \sum_i (ica_i^r.QD_i^r + ica_i^r.QMW_i^r + ica_i^r.QEW_i^r + ica_i^r.QER_i^r)$$

$$40. QQ_{comf}^r = \Theta_{comf}^r \sum_i QD_i^r$$

National labor markets

$$41. LS = \sum_r \sum_{for} LDS_{for}^r$$

$$42. w_s^{Inland} = (1 + \rho) w_s^{Costa}$$

$$43. LNS = \sum_r \sum_{for} LDNS_{for}^r + \sum_r \sum_{inf} LNS_{inf}^r$$

$$44. inc_{nf}^{Inland} = T. \left[\begin{aligned} & \frac{\sum_{for} LDNS_{for}^{Costa}}{w_{ns}^{Costa} \cdot \sum_{for} LDNS_{for}^{Costa} + \sum_{nf} LDNS_{nf}^{Costa}} + \\ & inc_{nf}^{Costa} \cdot \frac{\sum_{inf} LDNS_{nf}^{Costa}}{\sum_{for} LDNS_{for}^{Costa} + \sum_{nf} LDNS_{nf}^{Costa}} \end{aligned} \right]$$

$$45. LNS_{nf}^r = \Psi_{nf}^r \sum_{nf} LNS_{nf}^r$$

Interregional trade linkage

$$46. QM_{for}^{Costa} = QER_{for}^{Inland}$$

$$47. QM_{for}^{Inland} = QER_{for}^{Costa}$$

National current account balance

$$48. \sum_r \sum_{for} ER.PWM_{for}^r.QMW_{for}^r = \sum_r \sum_{for} ER.PEW_{for}^r.QEW_{for}^r + S_{row}$$

National savings–investment balance

$$49. \sum_r \sum_{for} PQ_{for}^r.QINVP_{for}^r + \sum_r \sum_{for} CDM_{for}^r = \sum_r \left(\sum_h S_h^r + S_G^r + S_K^r \right) + S_{row}$$

National Price index

$$50. Pindex^r = \sum_i \pi_i^r.PQ_i^r$$

$$51. ER = 1$$

3. Variables and parameters

VARIABLES

ER	Exchange rate
PD_a^r	Demand price for local commodities
$Pindex^r$	Regional consumer price index
PE_{for}^r	Composite export formal commodities price
PER_{for}^r	Regional export formal commodities price
PEW_{for}^r	Foreign export formal commodities price
PM_{for}^r	Composite import formal commodities price
PMR_{for}^r	Regional import formal commodities price

$LDNS_a^r$	Quantity of unskilled labor in activity a
LDS_{for}^r	Quantity demanded of skilled labor in formal sector activities
LS	Quantity supplied of skilled labor factor
LNS	Quantity supplied of unskilled labor factor
inc_{nf}^r	Average informal activities incomes
w_{for}^r	Average price of composite labor factor in formal activities
w_{ns}	Unskilled labor wage rate
w_s	Skilled labor wage rate

PMW_{for}^r	Foreign import formal commodities price	YK^r	Firms' revenue
PVA_a^r	Value-added activity price	Y_G	Government revenue
PQ_{for}^r	Composite formal commodities price	Y_h^r	Household h income
PX_{for}^r	Aggregate producer formal commodities price	$YINF^r$	Informal incomes
PWM_{for}^r	Foreign import price in foreign currency units	$YNSL^r$	Unskilled labor incomes
QD_a^r	Quantity of domestic supply of commodity a	YSL^r	Skilled labor incomes
QE_{for}^r	Quantity of composite regional and foreign formal commodities exports	S_h^r	Household h savings
QER_{for}^r	Quantity of regional formal commodities exports	S_G	Government savings
QEW_{for}^r	Quantity of foreign formal commodities exports	S_K^r	Firm savings
QM_{for}^r	Quantity of composite regional and foreign formal commodities imports	S_{row}	Foreign savings in local currency units
QMR_{for}^r	Quantity of regional imports formal commodities	EH_h^r	Household h consumption expenditures
QMW_{for}^r	Quantity of foreign imports formal commodities	$CQH_{h,a}^r$	Quantity of consumption of commodities for household h
QQ_{for}^r	Quantity of formal composite domestic and import formal commodities	CQG_{for}^r	Quantity of consumption of formal commodities for government
QX_{for}^r	Quantity of aggregate formal commodities output	$QINVP_{for}^r$	Quantity of fixed investment demand for formal commodities
\bar{K}_{for}	Quantity capital factor in formal activities	$Transf_h^r$	Transfers from government to households h
LD_{for}^r	Quantity demanded of composite skilled and unskilled labor from formal sector activities		

PARAMETERS

Ax_{for}^r	Formal production function efficiency parameter	δm_{for}^r	Armington regional-foreign function share parameter
δx_{for}^r	Formal production function share parameter	μm_{for}^r	Armington regional-foreign function exponent
μx_{for}^r	Formal production function exponent	σm_{for}^r	Armington regional-foreign function substitution parameter
αx_{for}^r	Formal production substitution parameter	τy_h^r	Direct tax rate on household h
γ_{nf}	Informal production productivity parameter	τk^r	Direct tax rate on factor capital
At_{for}^r	Composite formal labor function shift parameter	τm_{for}^r	Import tariff rate
δl_{for}^r	Composite formal labor function share parameter	τq_{for}^r	Sales tax rate
μl_{for}^r	Composite formal labor function exponent	$ica_{a,a'}^r$	Quantity of intermediate input a' per unit of product a
σl_{for}^r	Composite formal labor function substitution parameter	icd_{for}^r	Quantity of trade input per unit of formal domestic product.
At_{for}^r	CET domestic-export function shift parameter	icm_{for}^r	Quantity of trade input per unit of formal foreign imported product
δl_{for}^r	CET domestic-export function share parameter	icr_{for}^r	Quantity of trade input per unit of formal regional imported product
μl_{for}^r	CET domestic-export function exponent	ϕs_h^r	Share of household h in income of skilled labor factor
σl_{for}^r	CET domestic-export function substitution parameter	ϕns_h^r	Share of household h in income of unskilled labor factor
Ae_{for}^r	CET regional-foreign function shift parameter	ϕk_h^r	Share of household h in income of capital factor
δe_{for}^r	CET regional-foreign function share parameter	$c \min_{h,for}^r$	Subsistence consumption of formal commodity for household h
μe_{for}^r	CET regional-foreign function exponent	$pmc_{h,a}^r$	Marginal share of consumption spending on commodity a for household h
σe_{for}^r	CET regional-foreign function substitution parameter	mps_h^r	Marginal propensity to save for household h
Aq_{for}^r	Armington domestic-import function shift parameter	Θ_{commf}^r	Informal trade activity parameter
δq_{for}^r	Armington domestic-import function share parameter	T	Migration function parameter
μq_{for}^r	Armington domestic-import function exponent	ρ	Skilled wage premium between Costa and Inland
σq_{for}^r	Armington domestic-import function substitution parameter	Ψ_{nf}^r	Informal labor surplus distribution key
Am_{for}^r	Armington regional-foreign function shift parameter	π_a^r	Weight of commodity a in the consumer price index

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