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EVALUATION OF DEVELOPMENT POLICIES USING INTEGRATED BIO-ECONOMIC LAND USE MODELS: APPLICATIONS TO COSTA RICA

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Abstract

The paper presents a bio-economic land use model, REALM, to evaluate economic and agrarian policies influencing the agricultural sector within the Atlantic Zone of Costa Rica. REALM (Regional Economic and Agricultural Land-use Model is part of the SOLUS (Sustainable Options for Land Use) methodology developed since 1986 by the Research Program on Sustainability in Agriculture, a joint cooperation between Wageningen Agricultural University, the Ministry of Agriculture and Livestock of Costa Rica, and the Tropical Agricultural Research and Higher Education Center (CATIE). This methodology integrates two technical coefficient generators, one for cropping systems and one for pastures and livestock systems, a geographic information system and an optimization model. The objective of the methodology is to analyze land use at the regional level, taking into account economic and environmental objectives and restrictions. After a discussion of economic and agrarian policies in Costa Rica, the paper presents the main economic features of the REALM model for the Northern Atlantic Zone, the incorporation of endogenous prices of outputs and labor, and output price variation according to quality of roads and distance to markets. Both are related to the size of the region, while endogenous prices and wages are necessary because the supply originating in the region is capable to influence prices and wages, given downward sloping demand functions and an upward sloping labor supply function. The paper continues with evaluating a number of policy scenarios: taxing biocides to reduce environmental contamination, maintaining natural forests, reducing domestic public debt resulting in lower interest rates, and upgrading the road infrastructure; and a scenario to analyze the effects of real wage increases as a consequence of economic growth. It is shown that the REALM model within the SOLUS methodology is a suitable tool to analyze policy options to support policy makers, as well as to analyze future land use options in view of their effects for income and the environment.

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1. Introduction

Traditionally in most developing countries countries, issues surrounding the debate about the development of the agricultural sector center around the question of how to achieve a certain level of food security while simultaneously providing sufficient income for food producers (Timmer *et al.*, 1983). More recently, two other concerns have entered the debate, *i.e.*, sustainability and environmental protection (Kuyvenhoven *et al.*, 1995; Spiertz *et al.*, 1994). Even though objectives of agricultural development are potentially conflicting, they all have to do with land use. The way land is used has obvious implications for farm income and the various dimensions of sustainability and environmental impact. Environmental effects of agricultural production may include pollution through nutrient losses, negative externalities related to the use biocides (a generic term for all types of insecticides, herbicides, fungicides and nematocides), and trace gas emissions (Bouman *et al.*, 1998d), whereas sustainability is translated into soil nutrient balances.

In most developing countries, methodologies that are capable of simultaneously addressing the various dimensions of agricultural development (including quantifying the relationships between these different dimensions) are conspicuously lacking, thus seriously compromising informed decision making by policy makers. In this context, what is particularly important are the trade-offs that generally exist between economic, sustainability and environmental objectives (Crissman *et al.*, 1997). The main challenge in the development of such methodologies consists of the integration of bio-physical with socio-economic information. In this paper, we present such a methodology (called SOLUS, Sustainable Options for Land USe) developed by the Research Program on Sustainability in Agriculture (REPOSA) in Costa Rica. REPOSA is a joint cooperation between Wageningen Agricultural University (WAU) of the Netherlands, the Ministry of Agriculture and Livestock (MAG) in Costa Rica, and the Tropical Agricultural Research and Higher Education Center (CATIE) in Costa Rica. The SOLUS methodology evolved from the USTED (*Uso Sostenible de Tierras En el Desarrollo*; Sustainable Land Use in Development) methodology (Bouman *et al.*, 1998a). USTED operated initially at the level of a settlement of farm households (Schipper *et al.*, 1995; Stoorvogel *et al.*, 1995) and was gradually scaled-up via the district level (Jansen *et al.*, 1997a), towards the level of an entire region (Bouman *et al.*, 1998d).

In the subsequent sections of this paper we will (1) provide a brief overview of some of the currently available land use modeling methodologies, in order to place the SOLUS methodology in an adequate context; (2) indicate some relevant theoretical foundations which typically constitute the basis for government intervention; (3) discuss some of the major current economic and agricultural policy issues in Costa Rica in general and those relevant for the Atlantic Zone in particular, in order to link the policy scenarios evaluated with the SOLUS methodology with actual issues; (4) explain the contents of the SOLUS methodology with emphasis on the economic aspects; and (5) analyze the effects of a number of policy scenarios (in terms of aggregate land use and its associated economic, sustainability, and environmental indicators).

2. Land use analysis: different questions and methodologies

The term land use analysis, born out of the fruits of land evaluation and farming systems techniques (Fresco *et al.*, 1992), is often used for a wide variety of modeling exercises with significantly different objectives, methods, and levels of analysis (Fresco *et al.*, 1994). Different land use analysis methodologies can be identified based on four types of goals that are potentially relevant in relation to the identification and implementation of future land use options:

1. the projection of future land use for interpolation and extrapolation of trends;
2. the exploration of options for land use taking into consideration various economic and bio-physical factors;
3. identification and evaluation of policy instruments to realize particular options for sustainable land use; and
4. optimizing and supporting production and farming systems.

Methodology type 1 operates at the national or regional level and involves statistical analyses of past trends. A particular example of such a methodology, CLUE (Conversion of Land Use and its Effects), requires the development and use of dynamic geo-referenced land use cover models with which changes in land use cover are explained by a set of so-called land use drivers (Veldkamp and Fresco, 1996).

Methodology type 2 is aimed at identifying options for land use (in the medium-to-long term) while optimizing for various objectives, and to show the trade-off among these objectives. Such methodologies integrate knowledge on basic bio-physical (*e.g.*, climate, soil, crops and animals) and economic (*e.g.*, market) processes. Subsequently, this knowledge is confronted with agricultural, economic and ecological objectives, usually in linear programming models. Such methodologies allow the exploration of aggregate effects of alternative policies at the regional or national level, including possibilities to realize combinations of objectives as well as quantification of trade-off between objectives. An example of such a methodology is the SOLUS methodology as discussed in this paper (see also Bouman *et al.*, 1998a,d).

Methodology type 3 is aimed at efficient agricultural policies to induce certain desired changes in land use. This involves the explicit modeling of farmers' reactions to policy incentives given a range of land use options. This is typically done by combining programming techniques with econometric farm household models (Ruben *et al.*, 1994; Singh *et al.*, 1986).

Methodology type 4 involves the development and application of decision support systems in which the economic and ecological consequences of changes in production structure at the farm level are analyzed by evaluating the economic and agronomic management decisions on the farm. In case of large farms or plantations, a geographic information system (GIS) can be useful (Bouma *et al.*, 1995a).

Which of the above methodologies is the most appropriate depends on both the objectives and scale of the analysis. If the analyst is only interested in a studying an extrapolating past trends in land use changes and their 'drivers', statistical correlation techniques might suffice. On the other hand, if the goal is to explore the influence of certain agricultural policies and economic incentives on future land use patterns, both bio-physical and economic factors will have to be taken into account. One step further yet is when the interest is focussed on the behavioral response of individual farmers regarding their land use to certain sets of policy, in which case not only the production side but also farmers' utility considerations should be taken into account.

3. Theoretical aspects of agricultural policy implementation

Principles of agricultural policy making center around the issues of justification for government intervention; economic and institutional framework; and interactions between different government policies.

3.1 Justification for government policy interventions

The primary goal of agricultural policy is to influence land use decisions at the farm level. Government intervention is generally considered necessary wherever there exist market imperfections, market failure, or absence of markets. The latter usually has to do with property rights; for example, there typically do not exist systems that compensate economic actors for the negative externalities caused by biocide use of other actors. On the other hand, it is often inappropriate government intervention itself that causes market imperfections and/or market failure.

3.2 Economic and institutional framework for government intervention

Regional land use policies ideally should be based on an evaluation of the socio-economic and environmental implications of both actual and potential technological options for land use. This has been explicitly recognized by the Costa Rican government (SEPSA, 1997). Instruments of agricultural policy are often divided in price policies and market access policies (Ellis, 1992).

Price policies include tariffs and/or subsidies on certain specific production factors, agricultural inputs or outputs, and can be applied either in a direct manner or through exchange rate policies. Price policies, causing adjustments in relative prices, result in changes in the agricultural production structure, in such a way that the relatively cheaper production factors are used more intensively. The efficiency of agricultural pricing policies depends to a large extent on the possibilities that agricultural producers face to adjust their resource allocation without compromising profitability. For example, we will show below that, in the case of a policy aimed at reducing the environmental damage caused by biocides, a given reduction can be achieved more efficiently through a progressive biocide tax (*i.e.*, a tax that depends on the environmental damage caused by biocides) than through a flat tax (*i.e.*, a uniform percentage tax to each biocides).

Traditionally, government policies aimed at increasing agricultural output through increased adoption of improved agricultural technologies have focussed on input subsidies and interventions in output pricing, thus changing the structure of relative agricultural prices. However, under the influence of

Structural Adjustment Programs adopted in many developing countries, this type of government policy has become more and more unpopular as its distortive effects became more apparent, including maintaining inefficient production structures and increasing government deficits. In addition, imperfect (or even missing) markets for inputs (*e.g.*, imperfect markets for labor or capital) or outputs (*e.g.*, imperfect or missing markets for commercial export products) may put serious limitations on the scope for improving efficiency through adjustments in the production structure (de Janvry *et al.*, 1991).

Institutional policies generally aim at facilitating the access of agricultural producers to certain markets (for production factors as well as outputs) and/or services, and may include such diverse measures as land titling policies, labor market policies, and credit policies. Regarding the latter, besides credit subsidization which by now virtually has become a 'not done', the government itself may unwillingly put upward pressure on interest rates through the need to finance its current budget deficit as well as past accumulated deficits (*i.e.*, service its internal debt).

Government intervention, including marketing policies (including infrastructure investments) and rural extension policies, in itself may cause certain distortions to the extent that they are often biased towards areas with high agricultural potential and towards commercial and/or large producers (van de Walle and Nead, 1995).

3.3 Relationships between government objectives

Government objectives typically are various and may include income growth, food security, employment maximization, a more equal income distribution, minimum government deficit, positive balance of payments, conservation of natural resources, etc. While some of these objectives may be complementary (*e.g.*, food security and employment maximization), many often seem to involve negative trade-offs (*e.g.*, maximizing income growth and conservation of natural resources). Such trade-offs exist both at the level of policy (*e.g.*, deforestation permits generate income but destroy natural resources) as well as between private and social (or government) objectives, *i.e.*, private utility maximization is not always compatible with maximization of social benefits. An example, which receives ample attention in this paper, concerns the trade-off between agricultural income on the one hand, and sustainability and environmental effects on the other.

3.4 Modeling of effects of policy measures in the SOLUS methodology

Although it is recognized that ultimately land use decisions are taken at the farm level, the latter is often not modeled explicitly in the type 2 methodology, of which the SOLUS methodology (to be discussed below) is an example. Recognizing the importance of the farm level for land use decisions implies that factors such as knowledge level of the farmer, emphasis on short-term income maximization (and consequent relative neglect of long-term resource productivity considerations), neglect of negative externalities by individual farmers, and issues surrounding property rights, are important for policy analysis. However, all these factors are not directly taken into account in SOLUS. This, in turn, limits to some extent the type of scenarios and policies that can be evaluated with the SOLUS methodology. For example, while improved agricultural extension and market operation (both of which lead to better information for producers on which they base their input demand and output supply behavior) have been identified as promising strategies for improving small holder farming conditions (Jansen and van Tilburg, 1996; SEPSA, 1997). However, these effects cannot be adequately addressed with the SOLUS methodology. On the other hand, the latter is well qualified to explore, at the aggregate level of the region, the scope and possibilities of certain policy incentives to reach a certain desired land use pattern, taking simultaneously into account aspects of income, sustainability and environmental considerations.

4. Economic and agricultural policy in Costa Rica

4.1 The evolution of macro-economic policy

Historically, the Costa Rican economy has performed quite well. For example, according to Céspedes (1998), between 1957-1977, GDP per capita grew by an average rate of 2.7% per year (equivalent to a growth in total GDP of some 5.5% per year), with corresponding substantial improvements in social indicators[1] (*i.e.*, the percentage of households living in poverty decreased from 50% in 1960 to 25% in 1980, confirming the now firmly established positive correlation between economic growth and poverty reduction (Thomas, 1998), while the Gini coefficient of income distribution remained fairly stable through time at around 0.40-0.45). During the same period agricultural production (consisting nearly entirely of food production with coffee and banana as the two major export crops) also performed well, growing by over 4% per year (Celís and Lizano, 1993). To a large extent, the favorable economic performance of Costa Rica during this period was agriculture-led (OFIPLAN, 1982). In addition, Costa Rica has been able to largely avoid the tremendous instability (mainly reflected in very high rates of inflation and exchange rate fluctuations) which has characterized the economies of many Latin American countries and which has been a serious obstacle to higher savings rates as well as domestic and foreign investment (Celís and Lizano, 1993). Notwithstanding, growth in per capita GDP slowed dramatically to 0.3% per year for the period 1977-1997. This compares unfavorably with the performance of per capita GDP growth in Latin American countries which increased from 1.8% per year during 1980-85 to 3.2% during 1991-96 (World Bank, 1997). However, the improvement in economic performance in Latin America in the period 1991-96 compared to the performance during the years 1980-85 was also notable in Costa Rica. From 1985 to 1995, its GNP per capita increased with 2.8% per year (World Bank, 1997).

From the 1950s onwards and until 1983, Costa Rica's economic policy was largely based on the so-called import substitution model, aided by traditional agricultural export commodities and foreign aid. Salient characteristics of the import substitution model included strong direct government interference (*e.g.*, through enforcement of trade barriers, direct taxing of agricultural exports to generate resources to finance the subsidies granted to the industrial sector, protectionism in the service sector through the creation of public enterprises in air transportation, insurance and financial sector, telecommunications, energy etc.), high dependency on imported inputs, and discouragement of export initiatives. The latter mainly centered around the framework of the Central American Common Market (Rodriguez-Vargas,

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[1] Most social indicators already were good as early as 1950 as a result of social investments made in the decades before 1950 (Céspedes, 1998).

1994). However, concurrent with substantial economic growth, government expenditures as a % of GDP more than doubled between 1950 and 1980 (from 26 to 54%; Céspedes, 1998), mainly as a result of social programs (including health, education, programs for the disprivileged etc.) with corresponding increases in the tax burden and government's claim on available credit resources. Particularly after the first oil crisis in 1973, the Costa Rican government adopted a policy of starting large state-owned manufacturing, processing and transport companies; catalyzed by the second oil crisis in 1979, most of these state-owned companies failed[2]. The government's inability to generate sufficient revenues to match its expenses, a deterioration of the Central American markets (mainly due to warfare), increasing costs of the external debt created in the 1970s, and the inflexible government policy of adhering to a fixed exchange rate, led to the crisis beginning in the early 1980s (Rodriguez-Vargas, 1994; Jiménez, 1998). During the import substitution era (which lingered on for too long, effectively creating monopolies that depended on relatively small internal and regional markets), economic growth occurred primarily as a result of accumulation of production factors, rather than as a result of technological change and corresponding productivity increases (Robles, 1998). The latter became important again after 1984 with the introduction of the so-called export growth model in which increased competitive pressure and better access to new technologies led to a renewed role of productivity gains as the engine of economic growth. It was increasingly realized that the import substitution model implied many distortions (*i.e.*, reductions in consumers' purchasing power, misallocation of resources, discouragement of technological innovation, failure to achieve sufficient economies of scale, dependency on imported inputs and discouragement of exports, increase of foreign indebtedness etc.) which needed to be eliminated in the strive for better integration into the world market (Monge and Rosales, 1998). As a result, during the period 1983-1993 the Costa Rican economy was increasingly liberalized and a number of economic and financial reforms took place in order to better integrate Costa Rica into the overall world economy (*i.e.*, beyond Central America), often with the help from international financial institutions such as the World Bank, the Interamerican Development Bank, the International Monetary Fund (IMF), and the United States Agency for International Development. Structural reform consisted mainly of lowering of trade barriers, financial sector reform, and reform of the state sector. However, while international cross-country evidence clearly shows that changes in economic growth rates are highly correlated to the speed and extent of structural adjustment, both in Latin America (Hausmann, 1998) as well as in other parts of the world (Thomas, 1998), there exists a consensus that the implementation of these structural reforms (aimed primarily at

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[2] On the other hand, part of the growth in public investment realized during the 1970s went to agriculture, public utilities, financial services and education, all of which played an important role in the economic recovery experienced during the 1980s.

lowering inflation rates and balancing fiscal and external accounts) in Costa Rica has been both incomplete and insufficiently consolidated (Céspedes, 1998; Delgado, 1998; Hausmann, 1998; Jiménez, 1998; Mesalles, 1998; Monge and Rosales, 1998; Vargas, 1998). This is illustrated by the fact that inflation is not yet under control (still two digits), that the fiscal deficit, although it decreased from 5.3% of GDP in 1996 to 3.2% in 1997, is still well above the IMF target of 0.5%, and that the current account deficit runs at 5-7% of GDP (financed by influx of short-term capital from abroad). Thus, as of 1998, Costa Rica has neither yet completely abandoned the old economic model (based on import substitution and strong direct government interference) nor fully implemented the new model (based on comparative advantage principles of free trade, opening up the economy, diversifying the export base, and a reduced government that focuses on a facilitating role).

During the period 1994-97 it became increasingly obvious that the implementation of structural adjustment implicated certain costs (Mesalles, 1998). For example, interest rates surged (caused by restrictive monetary policy adopted after the closure of the *Banco Anglo* which costs had been financed monetarily, leading to high inflation rates) resulting in reduced investment which, combined with a contraction in consumption, caused a recession (GDP contracted by 0.6% during 1996, down from 2.4% growth in 1995 and 4.5% in 1994). As a result, the fiscal deficit did not improve between 1995 and 1996 (due to less government income and higher debt service payments), staying at around 5% of GDP. In Costa Rica, monetary policy has traditionally served fiscal policy, *i.e.* fiscal deficits caused by structural imbalances in the level and composition of government income and expenditure were usually financed inflationary by expanding the monetary base.

In 1997, some fruits of the adjustment efforts were harvested as evidenced by an increase in GDP to just over 3% for the year (or about 0.8% in per capita terms; Latin America Monitor, June 1998). An important factor was increased flexibility in monetary policy which after 1995 became less restrictive, leading to lower interest rates (Mesalles, 1998). Other important factors that contributed to this improved performance include the fact that the Figueres administration (1994-1998) exhibited budgetary restraint in its final year (unlike history in which governments typically surrender to a spending spree in election years) and the large investment by computer chip producer INTEL. During 1997, both inflation and real interest rates lowered, to respectively about 11.5% and less than 7%. However, the balance of payments and current account deficit increased (to some 4% of GDP), reflecting increased economic activity (higher imports of capital goods). The size of the internal debt (amounting to US$2.63 billion, or nearly 28% of GDP; Latin America Monitor, June 1998) remains problematic, with interest payments accounting for some 30% of total government expenditure[3] (Vargas, 1998).

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[3] In this context it is interesting to note that the difference between current government income and expenses (excluding

In conclusion, despite the slow and partial character of the adjustment process in Costa Rica, some degree of success was achieved: *e.g.*, economic growth has picked up, while the export base diversified; the unemployment rate has about halved (from 9% in 1980 to 4% in 1995); the government sector now accounts for about 45% of total GDP; foreign investment has increased from 2.8% of GDP in 1990 to 5% of GDP in 1997 (equivalent to some US $ 500 m). Along with these successes, no widespread bankruptcies did occur, the share of wages in GDP has not decreased (and has even increased to a small extent), and income distribution (as measured by the Gini coefficient) has not deteriorated. Indeed, even though public expenditures on social programs have decreased, most social indicators (education, infant mortality, life expectancy etc.) remain satisfactory. Nevertheless, the performance of the government sector is still quite problematic. For example, figures in Vargas (1998) indicate that whereas tax income between 1985 and 1997 has fluctuated between 14 and 17% of GDP (figure for 1997 is about 16-17% of GDP, with some 25 and 75% as direct and indirect taxes, respectively), government expenditure between 1985 and 1997 has fluctuated between 20 and 22% of GDP (1997 figure is 18% of GDP). Besides pushing up interest rates, the substantial interest payments on government debt (accounting for about 5% of GDP) imply crowding out of other (non-interest) expenditures such as education, infrastructure (badly in need of overhaul, particularly the road system), health etc. (Hausmann, 1998). This is the more serious since it is often claimed that government expenditures in education and health have a regressive character; indeed, Céspedes (1998) has shown that in general it is the middle class that has benefited most from the economic and social progress realized during the period 1950-1980. An example of policy failure that still has not been removed yet consists of the very high tariff duties (of on average 40%) on a large number of basic food products. These tariffs are highly regressive, effectively meaning a reduction exceeding 40% in the purchasing power of the 70,000 poorest households in Costa Rica (Céspedes, 1998).

4.2 Agricultural policy

Similar to macroeconomic policy in general, agricultural policy making in Costa Rica can be divided into two main periods, *i.e.*, pre-1980 and post-1980 (SEPSA, 1997). Before 1980 agrarian policies were directed primarily towards the production of traditional export crops such as banana, coffee, sugar cane, cacao and beef, along with self-sufficiency in the production of basic food crops for domestic consumption including maize, rice, beans, and sorghum (Celís and Lizano, 1993; Gonzalez, 1994). During most of the 1960-1980 era, fiscal and monetary policies towards the agricultural sector maintained

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debt service payments), also known as the primary deficit, is no longer negative, *i.e.*, the government deficit is now largely caused by interest payments on public debt.

a positive rate of protection, leading to a wide range of direct and indirect price distortions (Guardia *et al.*, 1987). Policies applied to achieve food security included regulation of input and output prices; infrastructural investments; technical assistance; (subsidized) credit facilities; and import and export regulation (Cartín and Piszk, 1980; Sain and López Pereira, 1997; Wattel and Ruben, 1992). Marketing of basic food crops was regulated by the parastatal National Production Council (CNP) which guaranteed fixed producers' prices for any quantity supplied. Most of the produce was sold on the domestic market at below these guaranteed producers' prices, with any surplus production exported to other Central American and Caribbean countries. Imports of basic food grains were only allowed in times of shortages (Guardia *et al.*, 1987). At the same time imports of inputs such as agrochemicals and agricultural machinery were taxed, thus providing an additional incentive for relatively input-extensive basic food crop production as compared to cash crop production. Investments in infrastructure not only included construction of roads and bridges but also investments in storage, purchase and sale centers by the CNP, as well as investments in research and extension infrastructure by the Ministry of Agriculture and Livestock (MAG). While MAG provided technical assistance focussing on the introduction of productivity-increasing technologies, the Agrarian Development Institute (IDA) turned many previously landless laborers into land owners by establishing settlements of small and medium-sized farms. Credit was mainly provided by the public banking system. However, by now it is officially recognized that the real issue with respect to credit is not so much quantity but rather access (SEPSA, 1997). Particularly with subsidized interest rates, access is typically biased towards large farmers, with small and medium-scale farmers often having to rely on expensive informal credit (Cartín and Piszk, 1980; Quirós *et al.*, 1997). Large farmers also benefited more from price support policies exercised by the CNP which played a much larger role in the rice market (dominated by large farmers) as compared to the maize and beans markets (dominated by small and medium scale farmers).

During the second half of the 1970s growth of agricultural production substantially slowed and it was increasingly realized that the size of the domestic market is too small to serve as a base for rapid and sustained growth of the agricultural sector. The main consequence for the agricultural sector of the market liberalization policies adopted as part of a series of structural adjustment programs introduced after 1980 was a much higher degree of integration into the world market (Pomerada, 1995; SEPSA, 1997). The system of guaranteed producer prices and consumer subsidies was gradually phased out, while production of agricultural export crops was promoted through a 100% reduction in export taxes to new markets, a 100% reduction in import taxes for inputs such as agrochemicals and agricultural equipment, as well as credits at favorable terms for export activities (Mora Alfaro *et al.*, 1994). These measures resulted in a strengthening of the comparative advantage of traditional export crops (*e.g.*, banana, coffee, sugarcane) relative to basic food crops, as well as in a promotion of non-traditional export crops (*e.g.*, pineapple, palm heart, flowers, ornamental plants, root and tuber crops). Overall, the dependence of total export earnings on banana and coffee decreased as a result of the stimulation of non-traditional export crops. Exports in general were further stimulated by the exchange rate policy which through a system of mini-devaluations aims at maintaining the competitive position of Costa Rica *vis-a-vis* its main trading partners. At the same time this exchange rate policy acts as a disincentive for (mainly small and medium-scale) farmers who produce for the local market only since they face higher production costs without being compensated by higher output prices (Mora Alfaro *et al.*, 1994).

The process of increased market liberalization and the changing focus of government assistance towards non-traditional export production left many small and medium-scale farmers in an adjustment crisis, with some of them even having had to abandon farming (Mora Alfaro *et al.*, 1994; SEPSA, 1997). In addition, it is sometimes claimed that since many non-traditional export crops are relatively input-intensive, the new emphasis on market liberalization led to increased environmental damage through soil nutrient depletion and contamination of soil and water resources (Kruseman *et al.*, 1994). From past experience of other countries (particularly those in Southeast Asia who experienced a combination of high economic growth at the expense of substantial environmental degradation), it is now well-known that economic growth does not guarantee sustainable development (Thomas, 1998). Indeed, there exists numerous arguments in favor of strategy of environment-friendly growth of agricultural productivity (instead of an exclusive focus on productivity growth first and cleaning up afterwards): the irreversible losses argument (*e.g.*, loss of biodiversity); high cleaning-up costs (avoidance strategies tend to be cheaper); possibilities for revenue enhancement (abolishing subsidies that promote environmental damage, and introduction of taxes according to the 'the polluter pays' principle); and optimal resource use (resource-conserving strategies are often more efficient than resource destruction). On the other hand, it has also been shown that, at least theoretically, the introduction and application of new technologies may result in positive, rather than the traditionally encountered negative trade-offs between economic and sustainability objectives (*i.e.*, lead to win-win situations in terms of simultaneously satisfying both economic and bio-physical sustainability; Bouman *et al.*, 1998a). This is particularly relevant for our study area (*i.e.*, the Atlantic Zone of Costa Rica) where a number of the non-traditional export crops are being produced.

In recent years, the pendulum has swung back to a certain degree, with renewed policy emphasis on food security-related issues including efficient basic food production, albeit without significantly compromising the attention for export-led agricultural growth (SEPSA, 1997). The system of export subsidies for non-traditional agricultural exports proved to be incompatible with international trade agreements and will be completely phased out by 1999. Concern for increasing rural poverty and degradation of the natural resource base led to the adoption of the concept of sustainable development as official government policy (Quesada Mateo, 1990; SEPSA, 1995). The role of the state is now meant to be that of a facilitator in a special program designated at improving the competitiveness of small and medium-scale farmers, with an annual budget of about US$ 13 million (La Gaceta, 1998). This program also aims at better organization and cooperation between such farmers in order to improve their bargaining position in the marketing of their produce which currently can be considered as quite weak (Jansen and van Tilburg, 1996); at improving their creditworthiness and access to formal loans; at the introduction of a quality certification system for export products; and at the development and transfer of modern agro-industrial technologies to increase the value added of export products. Similar policy directions were identified earlier by the Ministry of Agriculture and Livestock (SEPSA, 1997). It has been shown elsewhere through simulation modeling that, at least in the short run, this program is likely to be successful in raising both smallholder incomes and export production, even though at an environmental cost in terms of soil nutrient depletion and biocide use (Roebeling *et al.*, 1998).

5. Main economic aspects of the optimization model

The regional land use model of the Northern part of the Atlantic Zone of Costa Rica, is an 'upscaling' of the models for two smaller sub-regions, the *asentamiento* (settlement) Neguev (Schipper, 1996) and the *cantón* (county) Guácimo (Jansen and Stoorvogel, 1998). The latter models are linear programming models assuming exogenous (fixed) prices for inputs and outputs. In contrast, the size of the Northern part of the Atlantic Zone (NAZ) requires a different approach with regard to prices. This is explained in the next sections under the headings *location within the NAZ*, *downward sloping demand functions* and *upward sloping labor supply function*. However, first an overview is given of the SOLUS methodology, followed by a brief description of the NAZ.

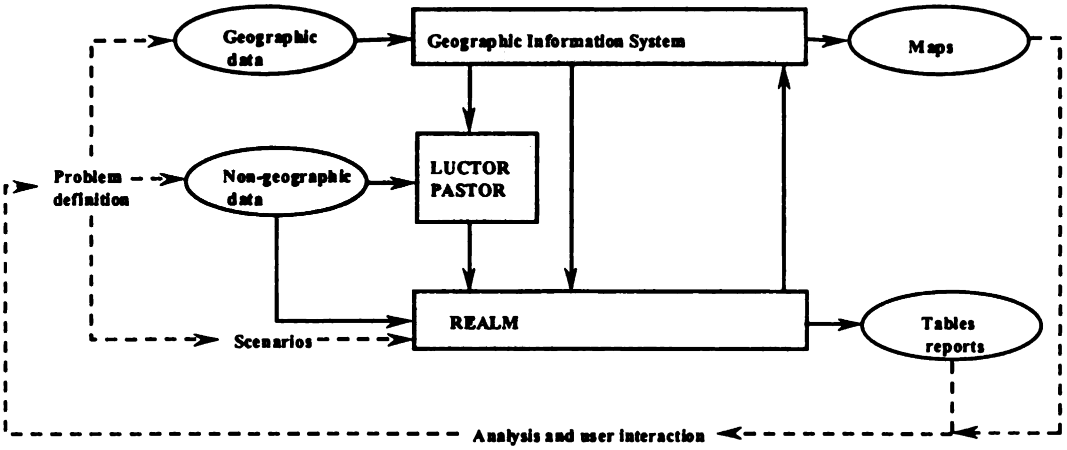

Figure 1 Overview of the SOLUS methodology

The SOLUS (Sustainable Options for Land USe) methodology involves the integration of a number of techniques and models, Figure 1. The core of the methodology consists of *i*) a linear programming model, called REALM (Regional Economic and Agricultural Land-use Model), *ii*) two Technical Coefficient Generators, one for cropping activities called LUCTOR (Land Use Crop Technical coefficient generatOR) and one for livestock activities called PASTOR (Pasture and Animal System Technical coefficient generatOR), and *iii*) a Geographic Information System (GIS). Linear programming models are often used in exploratory land use studies (e.g. de Wit *et al.*, 1988; Hazell and Norton, 1986; Rabbinge and van Latesteijn, 1992; Veeneklaas *et al.*, 1994), as such models allow for the integration of knowledge on bio-physical and socio-economic processes.

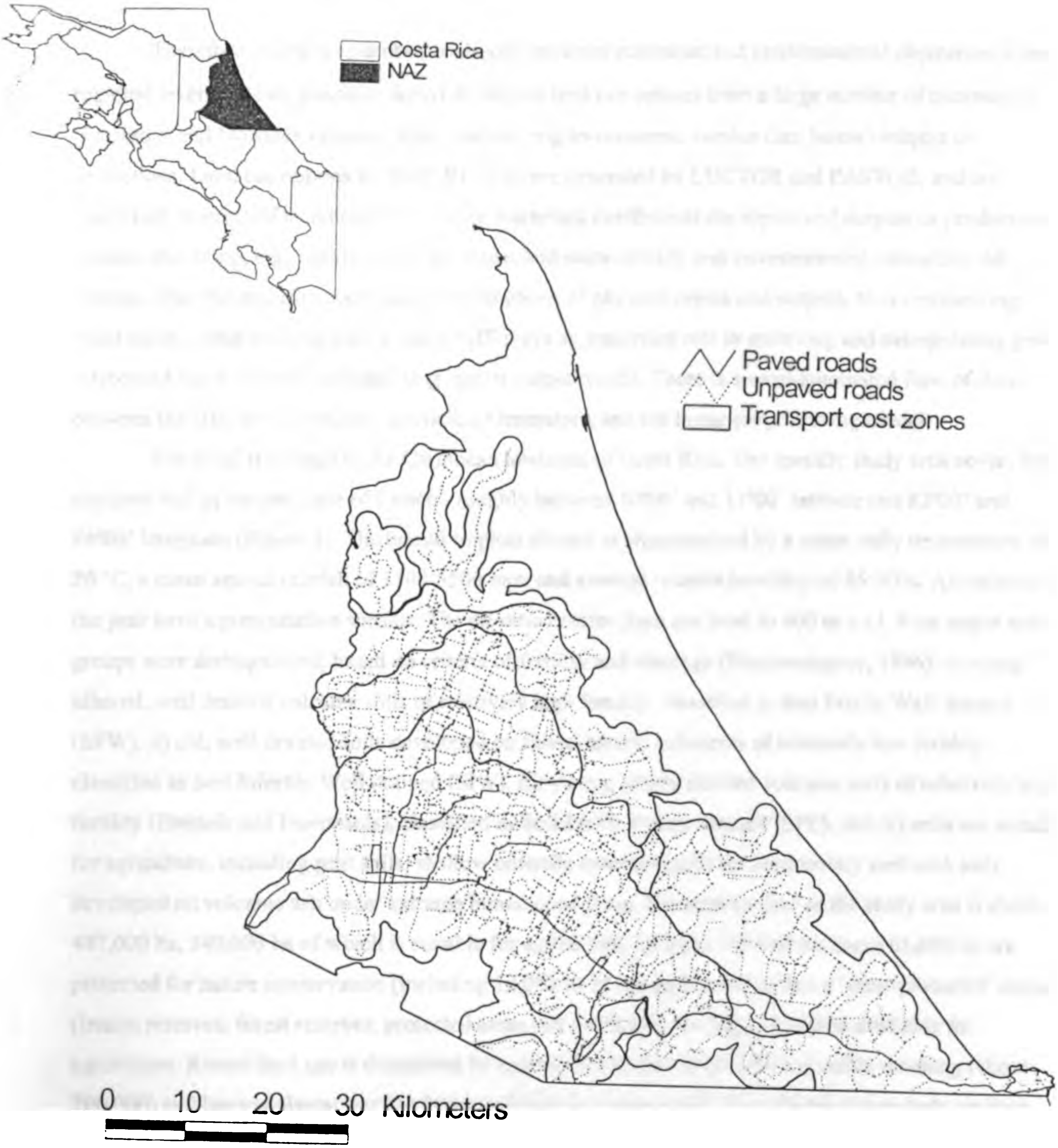

Figure 2 Map of Northern Atlantic Zone in Costa Rica with 12 sub-regions and road infrastructure

Therefore, the assessment of trade-offs between economic and environmental objectives at the regional level becomes possible. REALM selects land use options from a large number of alternatives (*i.e.*, crops and livestock options) while maximizing an economic surplus (see below) subject to restrictions. Land use options to 'feed' REALM are generated by LUCTOR and PASTOR, and are quantified in terms of technical coefficients. Technical coefficients are inputs and outputs of production systems including, e.g., yields, costs, labor use, and sustainability and environmental indicators. All systems describe specific quantitative combinations of physical inputs and outputs, thus representing fixed input-output technologies. Finally, GIS plays an important role in archiving and manipulating geo-referenced input data and in presenting spatial output results. There is a semi-automated flow of data between the GIS, the Technical Coefficient Generators, and the linear programming model.

The NAZ is located in the Caribbean lowlands of Costa Rica. The specific study area covers the northern half of the province of Limón , roughly between 10°00' and 11°00' latitude and 83°00' and 84°00' longitude (Figure 2). The humid tropical climate is characterized by a mean daily temperature of 26 °C, a mean annual rainfall of 3500-5500 mm, and average relative humidity of 85-90%. All months of the year have a precipitation surplus. The elevation varies from sea level to 400 m a.s.l. Four major soil groups were distinguished, based on criteria of fertility and drainage (Nieuwenhuyse, 1996): *i*) young alluvial, well drained volcanic soils of relatively high fertility, classified as Soil Fertile Well drained (SFW), *ii*) old, well drained soils developed on fluvio-laharic sediments of relatively low fertility, classified as Soil Infertile Well drained (SIW), *iii*) young, poorly drained volcanic soils of relatively high fertility (Entisols and Inceptisols), classified as Soil Fertile Poorly drained (SFP), and *iv*) soils not suitable for agriculture, including peat soils, shallow unfertile mountain soils on sedimentary rock and soils developed on volcanic ash under extreme humid conditions. The total surface of the study area is about 447,000 ha, 340,000 ha of which is suitable for agriculture. Of these 340,000 ha, some 61,000 ha are protected for nature conservation (including 12,000 ha of national parks) or has a 'semi-protected' status (Indian reserves, forest reserves, protected areas and wetlands), leaving 279,000 ha available for agriculture. Recent land use is dominated by natural forests (about 191,000 ha), cattle ranching (about 200,000) and banana plantations (33,000 ha); secondary crops (total about 23,000 ha) include plantain, palm heart, root and tuber crops, maize, papaya, pineapple and ornamental plants.

5.1 Location within the NAZ

Prices of inputs and outputs depend on geographical location within the NAZ, due to variation in distance to markets and quality of roads. Market prices for outputs are related to these parameters. Likewise, wages in the different sub-regions are related to an estimation of the travel costs for labor between the sub-regions. However, prices for agricultural inputs (e.g., seed, fertilizer and biocides) are assumed to be the same in each sub-region as research by REPOSA showed only minor differences in input prices across shops in the NAZ.

The geographical variation in product prices is simulated in REALM by dividing the NAZ into 12 sub-regions, each with its own specific transport costs (based on geographical distance and quality of roads) to the most relevant market (depending on the type of product and final destination). These transport costs are calculated on the basis of a regression model estimated by Hoekstra (1995), similar as in Jansen and Stoorvogel (1998). The sub-regions are the result of a GIS-overlay of three zonification maps based on equal transport costs (Bouman *et al.*, 1998c). The first map concerns the transport costs of agricultural products for the domestic market to the intersection of the Limón-San José road with the road to Puerto Viejo, close to the entrance of the Braulio Carillo national park. The second concerns livestock products to the same intersection. The third relates to export products and shows the transport costs to the Limón harbor. Depending on the number of iso-transport costs lines, such an overlay results in more or less sub-regions. To keep the size of the model within limits, while still distinguishing meaningful transport zones, 12 sub-regions were delineated (Figure 2).

5.2 Downward sloping demand functions

For a number of products, the share of the NAZ in the national supply is considerable. Therefore, prices of these products are likely to be influenced by the supply from the NAZ given the limited demand for these products. This applies to bananas, palm heart, plantain and animals (meat) presently considered in the model, and would also apply to products like coconut, *guanábana* (sour sop), papaya, *pejibaye* (fruits of the palm heart tree) and *pipa* (fresh coconuts). For some products (*i.e.* palm heart and bananas) the supply from the NAZ is even a considerable part of the world supply. In these cases product prices become endogenous, determined by demand and supply. Based on research in Brazil (Kutcher and Scandizzo, 1981), Mexico (Duloy and Norton, 1973, 1983) and elsewhere, Hazell and Norton (1986) present a methodology to incorporate variable prices in linear programming models. Downward-sloping demand functions, based on econometrically estimated price-demand elasticities are linearized around an observed base quantity and price. Celís (1989) used the same technique in an agricultural sector model for Costa Rica.

The relation between product prices and supply from the NAZ region is incorporated in REALM by estimating demand functions for a number of relevant products. For these products, the price P_j is a function of quantity Q_j. Even with a simple linear inverse demand function, $P_j = a_j - b_j * Q_j$, the linear programming model would become a quadratic model. Even though models with quadratic forms in the objective functions can be solved with modern software packages, including GAMS (Brooke *et al.*, 1992), in which the present model is written, they require (much) more solution time than linear models, particularly in the case of large models such as REALM. Therefore, we opted for a linear approximation method.

In models where prices are exogenous, the value of production ($p_j * Q_j$) is part of the objective function, as are the costs of production in terms of current inputs and labor costs. By maximizing the difference between the value of production and the costs of production the *producer* surplus is maximized, as occurred in the sub-regional models for the Neguev (Schipper, 1996) and Guácimo (Jansen and Stoorvogel, 1998). In the regional NAZ model, on the other hand, the area below the demand function of each product is calculated at different prices. These areas less the costs of production represent the sum of the *producer* and the *consumer* surplus at different price-quantity combinations of a product. The linear programming model selects those price-quantity combinations for all products that, taken together, maximizes the sum of the *producer* and the *consumer* surpluses.

A number of assumptions had to be made. The inverse demand functions are linear of the form:

$$P_j = a_j - b_j Q_j \qquad (1)$$

in which P_j is the price of commodity j and Q_j is the quantity demanded, while a_j (intercept on P_j axis) and b_j (slope) are coefficients. Dropping the subscript j, each demand function has a price elasticity η at point (P^0,Q^0). Given equations 2 and 3, coefficients a and b are calculated in equations 4 and 5. Knowledge of the price elasticity at a certain point, for example in a base year, thus allows us to calculate the coefficients a and b.

$$\eta = \frac{dQ/Q}{dP/P} \qquad (2)$$

$$b = -dP/dQ \qquad (3)$$

$$b = \frac{-P}{\eta Q} \qquad (4)$$

$$a = P + bQ \qquad (5)$$

Having calculated the coefficients a and b, one can divide the demand function into a number of segments. Associated with each segment-limit d will be a dimensionless variable D^d, which is be forced to take on values between 0 and 1.

In the NAZ model the demand functions are divided into 100 segments over a length from Q^0/k to k*Q^0, as suggested by Norton (1995)[4]. For each of the segment-limits Q^d, one can calculate the price P^d, producer revenue R^d, and the area below the demand function W^d, as follows:

$$P^d = a - b\,Q^d \qquad (6)$$

$$R^d = P^d\,Q^d \qquad (7)$$

$$W^d = a\,Q^d - 0.5\,b\,(Q^d\,)^2 \qquad (8)$$

Quantity Q^d, producer revenue R^d and the area below the demand function W^d are *coefficients* to be associated with the segment-limit variables D^d.

The above equations apply to a country as a whole. In case of the NAZ model the situation is more complicated as we should take into account not only the supply originating from the NAZ, but also the supply from other regions in Costa Rica, as well as, in case of export products, the supply from other countries. Under these conditions, the demand function facing the producers within the NAZ is different from the national demand function. It can be shown (Hazell and Norton, 1986) that the regional demand elasticity η_r can be expressed as follows:

$$\eta_r = \eta \frac{1}{K} - \sigma_{nr} \frac{1-K}{K} \qquad (9)$$

In this equation η represents the national demand elasticity, K is the share of the NAZ production in the national production and σ_{nr} is the supply elasticity from other regions than the NAZ.

The necessary calculation assignments are executed in GAMS, following suggestions of Norton (1995) for similar calculations using a spreadsheet program. The parameters used for each product are a base price and quantity, a price demand elasticity, the share of the supply from the region in the national supply (under the base situation) and a price supply elasticity of the remaining regions (i.e, regions outside the model)[5]. Price demand elasticities used are taken from Geurts *et al.* (1997) and van der Valk (1998). Base price and quantities, including the share of the region in the national supply, are based on 1996 data.

In the current version of REALM, price supply elasticities are not estimated, but assumed to be

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[4] Norton (1995) suggests k=3, in order to stay in the 'neighborhood' of the point (Q^0, P^0). However, in the present model k can be different for each product as for exportable products, such as bananas and palm heart, 3*Q^0 is not 'long enough' to avoid effectively an upper bound on the exportable quantity.

[5] In the case of export products rather than the supply of other regions within Costa Rica, supply from other countries is often more important. So, one also has to estimate the share of Costa Rica in (the relevant part of) the world market and the supply elasticity of producers in these other countries.

0.7. Other studies suggest that supply elasticities between 0.4 and 1.0 are not unreasonable (Mamingi, 1997; Sadoulet and de Janvry, 1995). Norton (1995), on the basis of Henneberry (1986), suggests long-run supply elasticities of 1.0. However, using high elasticities might have the effect of 'driving out of the market' of other regions, because (much) lower prices are still economically attractive for producers in the NAZ (at least according to the programming model). Future versions of the REALM model will contain empirically estimated supply elasticity values which have recently become available (unpublished work by Peter Roebeling and Hans Jansen).

5.3 Upward sloping labor supply function

Labor available for agriculture, and the remuneration for labor, has a considerable influence on production possibilities. Apart from an estimation of the current labor availability for agriculture within the region, it is assumed that the agricultural sector can attract labor from outside the sector which quantity depends on the wage the sector is willing to pay. Consequently, the model contains a linearized (upward sloping) labor supply function.

With regard to incorporating labor supply, Schipper (1996) demonstrates that labor constraints have an important impact on land use decisions. In general it could be argued that given a certain structure of land units and land use types, the costs and availabilities of factors of production *other than land* determine the use of land. In the original Neguev and Guácimo models both labor supply and wages were assumed to be fixed. This leads to undesirable results (Schipper, 1996; Jansen and Stoorvogel, 1998).

In contrast, in the NAZ model, it is assumed that in each sub-region there is a certain amount of labor working in agriculture at a fixed wage (the 'agricultural labor force')[6]. This labor can also work in the other sub-regions, be it that in that case transaction costs are taken into account.

Furthermore, labor not belonging to the agricultural labor force can also work in the agricultural sector. In this case transaction costs are taken into account as well; these transaction costs are, in general, higher than the transaction costs for labor already working in the NAZ agricultural sector. However, how

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[6] This agricultural labor force is estimated for each district on the basis of the agricultural labor force in 1984 (DGEC, 1987), taking into account the population in 1996, based on the vegetative population growth between 1984 and 1996 (annual registration of births and deaths; DGEC, 1997a) and the estimated migration to each county, based on the assumption that the migration rates between 1979 and 1984 are still applicable between 1984 and 1996. The outcomes were compared with more recent survey information at the level of the Atlantic Zone as a whole (DGEC, 1997b) and not deemed to be unreasonable. Subsequently labor force estimations per district were distributed over the 12 sub-regions on the bases of population density estimations, using a GIS.

much 'outside' labor is supplied depends not only on transaction costs, but also on a labor supply function in which labor supply is a function of the wage. In the current version of the REALM model, it is assumed that the total labor supply function (viz. the sum of the agricultural labor force and the non-agricultural labor force) is a non-smooth, cornered curve. Up to a well-defined supply (as a first assumption up to the currently available agricultural labor force, employed or unemployed) the wage is fixed at the present market wage, thereafter the function is linear but upward sloping.

As with agricultural products, the market for agricultural labor in the NAZ is only a part of the national labor market. Therefore, the national labor supply elasticity has to be adjusted before it can be applied. Apart from the share of the NAZ agricultural labor market in the national labor market (about 5%), the reaction on labor *demand* in *other sectors/regions than the NAZ agricultural sector*, caused by an increased labor *supply* to the NAZ agricultural sector, leading to increased wages, has to be taken into account. In analogy to the situation for product markets (see above), the following relation can be shown to exist (assuming no obstacles to labor mobility exist other than the previously mentioned transaction costs):

$$\varepsilon_r = \varepsilon \frac{1}{M} - \theta_{nr} \frac{1-M}{M} \qquad (10)$$

where ε_r is the labor supply elasticity for sector/region r, ε is the national labor supply elasticity, θ_{nr} is the labor demand elasticity in the remainder of the economy, and M is the share of the labor in sector/region r in the national labor market.

In the current version of REALM, at the national level a wage labor supply elasticity of 0.2 has been assumed, which is not out of line with other studies (Bosworth *et al.*, 1996). However, recent empirical work in Costa Rica based on 1996 survey data has produced an estimate of 0.4 (Hans Jansen, personal communication). With regard to the labor demand elasticity in the remainder of the economy, -0.5 would be a plausible approximation (Bosworth *et al.*, 1996). Using equation 10, and in view of a labor share of 0.05, an ε_r of 13.5 for the labor supply elasticity in the NAZ agricultural sector would thus be a reasonable approximation. Such an elasticity implies a very gently upward sloping labor supply function, in case more labor would be required than presently available (*i.e.*, after the horizontal part of the labor supply function).

The effect of this method is that the agricultural sector in the NAZ can use more labor than the estimated agricultural labor force, be it at (slowly) increasing wages. In this way the NAZ agricultural sector competes for labor with other economic sectors and regions. Furthermore, the fixed wage (horizontal line) at the lower tail of the labor supply function ('before the vertex') incorporates the institutional feature of the labor market that no labor is supplied at wages below the current wage level.

That is, wages can only stay the same or increase, i.e., are 'downward sticky'.

The above assumptions allow for the calculation of a labor supply function at different labor supply / wage points. Such an approach makes it possible to linearize the resulting labor supply function in a way similar to the linearization of product demand functions (Hazell and Norton, 1986). Following the Hazell and Norton (1986) discussion about endogenous input prices, labor is valued at the *average* wage, rather than at the marginal wage the model would be willing to pay (Bell *et al.*, 1982). Total labor costs are calculated as the area below the labor supply function at the optimal labor supply / wage point (the coefficient ϖ_o^o in the objective function of the model in Table 1). However, the approach followed here differs in two other points from the one in Hazell and Norton (1986). First, the labor supply function is not upward sloping linear over the entire relevant range of supply, but rather with a vertex. Secondly, the labor supply from outside the agricultural sector comes on top of the labor supply from inside the agricultural sector, comparable to the approach followed by Kutcher (1983). This additional labor is supplied at a fixed wage rate, but is limited in each sub-region of the NAZ. However, as also explained above, this labor can also be hired from other sub-regions, be it at certain transactions costs (Hazell and Norton, 1986), which are related to 1996 bus fares between the sub-regions.

The relevant part of the - simplified - REALM model is shown in a mathematical representation in Table 1, to demonstrate the approach to modeling the domestic and the export market, the labor market, and the livestock-pasture interaction. The symbols used are defined in three tables following the equations: indices in Table 2, variables in Table 3 and coefficients in Table 4.

REALM is written in GAMS (Brooke *et al.*, 1992); the version described in this paper (REALM4.0) is listed in Appendix 1 with data files in Appendix 2, except for the technical coefficients as generated by PASTOR and LUCTOR, see Section 5.5.

Table 1 Relevant part of - simplified - NAZ model

Objective function: benefits less costs: area below domestic demand functions plus value of exports, less product market transaction costs, less value of current input and labor costs (wage sum, transaction costs and area below labor supply function)' (¢ year^{-1})

$$\begin{aligned}\text{Max } Z = \sum_{j\in J1} p_{j\in J1}\, D_{j\in J1} + \sum_{j\in J2} p_{j\in J2}\, E_{j\in J2} + \sum_{j\in J3}\sum_{d} \omega^{d}_{j\in J3,d}\, D^{s}_{j\in J3,d} + \sum_{j\in J4}\sum_{d} \rho^{x}_{j\in J4,d}\, E^{s}_{j\in J4,d} \\ -\sum_{z}\sum_{j} t^{p}_{jz}\, S_{jz} - p\, C - \sum_{z}\sum_{\zeta} t^{l}_{\zeta z}\, L_{\zeta z} - \sum_{z} t^{o}_{z}\, O_{z} - \sum_{o} \varpi^{o}_{o}\, O_{o}\end{aligned} \tag{1}$$

Subject to:

- balances of product annuity per product per sub-region (ton year^{-1})

$$\sum_{s}\sum_{l}\sum_{t} - y_{jslt}\, X_{zslt} + \sum_{h} - y_{jh}\, A_{zh} + S_{jz} \leq 0 \quad \text{all } j, z \tag{2}$$

- balances of product annuity per product for whole NAZ (ton year^{-1})

$$S_{j} - \sum_{z} S_{jz} \leq 0 \qquad \text{all } j \tag{3}$$

- balance per product: domestic demand + export < production (ton year^{-1})(excluding imports as not relevant for the products concerned)

$$D_{j} + E_{j} - S_{j} \leq 0 \quad \text{all } j \tag{4}$$

- segmentation of domestic demand per product (ton year^{-1})

$$- D_{j} + \sum_{d} q^{d}_{jd}\, D^{s}_{jd} \leq 0 \qquad \text{all } j \in J3 \tag{5}$$

- convex combination constraint for domestic demand segment-limits variables

$$\sum_{d} D^{s}_{jd} \leq 1 \quad \text{all } j \in J3 \tag{6}$$

- segmentation of export demand per product (ton year^{-1})

$$- E_{j} + \sum_{d} q^{x}_{jd}\, E^{s}_{jd} \leq 0 \quad \text{all } j \in J4 \tag{7}$$

- convex combination constraint for export demand segment-limits variables

$$\sum_{d} E^{s}_{jd} \leq 1 \quad \text{all } j \in J4 \tag{8}$$

Table 1 Relevant part of - simplified - NAZ model, continuation

- annuity of inputs (sum of current inputs costs) balances per sub-region (¢* 1000 year^{-1})

$$\sum_s \sum_l \sum_t c_{slt}\ X_{zslt} + \sum_h c_h\ A_{zh} + \sum_s \sum_p \sum_r c_{spr}\ P_{zspr} + \sum_f c_f\ F_{zfm} - C_z \leq 0 \qquad \text{all } z \tag{9}$$

- annuity of inputs (sum of current inputs costs) balances for whole NAZ (¢* 1000 year^{-1})

$$-C + \sum_z C_z \leq 0 \tag{10}$$

- feed balance per nutrition type, per period per sub-region (Mcal year^{-1}; kg year^{-1})

$$\sum_p \sum_s \sum_r n_{sprmn}\ P_{zspr} + \sum_f n_{fn}\ F_{zfm} - \sum_h n_{hnm}\ A_{zh} \geq 0 \qquad \text{all } z, n, m \tag{11}$$

- animal stock balance for pastures and herds per sub-region (animal units year^{-1})

$$\sum_p \sum_s \sum_r s_{spr}\ P_{zspr} - \sum_h h_h\ A_{zh} = 0 \qquad \text{all } z \tag{12}$$

- balance of calves (ton year^{-1})

$$\sum_z y_{j=\text{calves},h=\text{breeding}}\ A_{z,h=\text{breeding}} - \sum_z \sum_h v_{h=\text{fattening, double purpose}}\ A_{z,h=\text{fattening, double purpose}} \geq 0 \tag{13}$$

- use of land units per sub-region per farm type by LUSTs (ha year^{-1})

$$\sum_l \sum_t X_{zfslt} + \sum_p \sum_r P_{zspr} \leq b_{zs} \qquad \text{all } z, s \tag{14}$$

- annuity of labor use balanced by labor supply per sub-region (days year^{-1})

$$\sum_s \sum_l \sum_t l_{slt}\ X_{zslt} + \sum_h l_h\ A_{zh} + \sum_s \sum_p \sum_r l_{spr}\ P_{zspr} + \sum_f l_f\ F_{zfm} - \sum_\zeta L_{z\zeta} - O_z \leq 0 \qquad \text{all } z \tag{15}$$

- agricultural labor force availability per sub-region (days year^{-1})

$$\sum_z L_{z\zeta} \leq a_\zeta \qquad \text{all } \zeta \tag{16}$$

Table 1 Relevant part of - simplified - NAZ model, continuation

- calculation of use of agricultural labor force for whole NAZ (days year^{-1})

$$\sum_{z}\sum_{\zeta} L_{z\zeta} - L \leq 0 \tag{17}$$

- segmentation of labor supply function (days year^{-1})

$$L + \sum_{z} O_z - \sum_{o} o_o \, O_o \leq 0 \tag{18}$$

- convex combination constraint for labor

$$\sum_{o} O_o \leq 1 \tag{19}$$

- calculation of environmental indicators per soil type per sub-region per indicator (kg year^{-1}; index year^{-1})

$$\sum_{l}\sum_{t} \delta_{slte} \, X_{zslt} + \sum_{p}\sum_{r} \delta_{spre} \, P_{zspr} - A_{sze} = 0 \qquad \text{all } s, z, e \tag{20}$$

- limit to environmental indicator per sub-region per soil type per indicator (kg year^{-1}; index year^{-1})

$$A_{sze} \leq d_{sze} \qquad \text{all } s, z, e \tag{21}$$

- limit to environmental indicator per sub-region per indicator (kg year^{-1}; index year^{-1})

$$\sum_{s} A_{sze} \leq d_{ze} \qquad \text{all } z, e \tag{22}$$

- limit to environmental indicator per soil type per indicator (kg year^{-1}; index year^{-1})

$$\sum_{z} A_{sze} \leq d_{se} \qquad \text{all } s, e \tag{23}$$

- limit to environmental indicator per indicator for whole NAZ (kg year^{-1}; index year^{-1})

$$\sum_{s}\sum_{z} A_{sze} \leq d_{e} \qquad \text{all } e \tag{24}$$

Table 2 Part of indices in NAZ model

indices	description	elements
j	products	depends on selection of LUSTs; the set *J* with elements *j* has four sub-sets: *J1*, products for domestic market without a market limitation; *J2*, products for export market without a market limitation; *J3*, products for domestic market with a downward-sloping demand function; and *J4*, products for export market with a downward-sloping demand function In the GAMS formulation this index is a combination between index C(PA) for crops (land use types) and index Q (product type/quality), or index HP(PA) for livestock product and the same index Q
d	segment-limits	1 to 100 in case of demand for products
z	sub-region	1 to 12, for sub-regions Rxxx; there is also index ζ as an alias for *z*
s	soil types	SFP, SFW, SIW
l	land use types	depends on selection of LUSTs, at present: pineapple, palm heart, melina, banana, plantain, cassava, (black) beans, teak, maize (corn), maize (cobs)
t	technology	depends on level (high/low) of fertilizer, biocides, herbicides and mechanization and on length of crop cycle (01, 02, 03, 10 or 15 years)
h	herd type	herds of 50 animals, either breeding, fattening or double purpose
p	pasture	depends on pasture (Brachiaria, Estrella, Natural, Brachiaria/Aracis pintoi, Tanner), weeding type (only herbicides, manual/herbicides, only manual) and fertilization level (low to high)
r	stocking rate	low to high, at present: 1 to 5 animal units per ha
f	feed types	Molasse of sugar cane, rejected bananas, *galinaz engorde*, P_2O phosphorus
n	nutrition types	Metabolizable energy, crude protein, phosphorus
m	period	season 1 (dryer): January to March, season 2 (wetter): April to December
o	segment limit	1 to 100 in case of labor supply
e	environmental indicator	N balance, P balance, K balance, N denitrification, N leaching, N valorization, biocide active ingredient, biocide indicator

Table 3 Part of variables in NAZ model

variables[1]	description	unit of measurement
Z	value of objective function	¢ year^{-}
S_j	annuity production per product	ton year^{-1}
S_{jz}	annuity production per product per sub-region	do
D_j	domestic demand per product	do
${D_{jd}}^d$	domestic demand segment limit variable per product	
E_j	export demand per product	ton year^{-1}
${E_{jd}}^x$	export demand segment limit variable per product	
C	annuity of current input use (materials and services)	¢ * 1000 year^{-1}
C_z	annuity current input use per sub-region	do
X_{zslt}	LUSTs (Land Use System & Technology) per sub-region per soil per land use type per technology	ha year^{-1}
P_{zspr}	PASTs (PASTure activity) per sub-region per soil type per pasture type per stocking rate	ha year^{-1}
F_{zfm}	FASTs (Feed Acquisition System & Technology) per sub-region per supplementary feed type per period	Mcal year^{-1}; kg year^{-1}
A_{zh}	APSTs (Animal Production System & Technology) per sub-region per herd type	herds year^{-1}
$L_{z\zeta}$	annuity of use of labor from the 'agricultural labor force' per sub-region z, originating from sub-region ζ	days year^{-1}
L	annuity of use of labor from the 'agricultural labor force' for whole NAZ	do
O_z	annuity of use of labor not belonging to the 'agricultural labor force' per sub-region	do
O_o	segment limit variable for total labor supply	
A_{sze}	environmental indicator variable per soil type per sub-region per indicator type	kg year^{-1}; index year^{-1}

[1] All variables in the model are continuous and larger than, or equal to, zero, except for Z and A_{sze} which are 'free' variables (larger than minus infinity). Furthermore, ¢ = *Colón*, the currency unit of Costa Rica.

Table 4 Part of coefficients in NAZ model

coeffi-cients	description	units of measurement
p_j	product price per product (OBJ)[1]	¢ ton^{-1}
p	price of current inputs and (reservation) wage (OBJ)	¢¢$^{-1}$$1000^{-1}$
t_{jz}	product market transaction costs per product per sub-region (OBJ)	¢ ton^{-1}
$\omega_{jd}{}^d$	areas below domestic demand function related to each segment limit of domestic demand functions (OBJ)	¢ year^{-1}
$\rho_{jd}{}^x$	producer revenue related to each segment limit of export demand functions (OBJ)	¢ year^{-1}
$q_{jd}{}^d$	quantity of domestic demand related to each segment limit of domestic demand functions	ton year^{-1}
$q_{jd}{}^x$	quantity of export demand related to each segment limit of export demand functions	ton year^{-1}
$t_{\zeta z}{}^l$	agricultural labor force transaction cost from sub-region ζ to sub-region z (OBJ)	¢ day^{-1}
w	wage of agricultural labor force (OBJ)	¢ day^{-1}
$t_z{}^o$	transaction costs for labor from outside the agricultural sector (OBJ)	¢ day^{-1}
$\__o{}^o$	area under total labor supply function sector (OBJ)	¢ day^{-1}
y_{jslt}	annuity yield of a LUST[2] per product	ton ha^{-1}
y_{jh}	annuity yield of an APST[3] per product	ton herd^{-1}
c_{slt}	annuity use of current inputs by a LUST	¢ * 1000 ha^{-1}
c_h	annuity use of current inputs by an APST	¢ * 1000 herd^{-1}
c_{spr}	annuity use of current inputs by a PAST[4]	¢ * 1000 ha^{-1}
v_h	calves as input for APST in case of fattening or double purpose	ton herd^{-1}
c_f	annuity use of current inputs by a FAST[5] .	¢ * 1000 kg^{-1}
n_{sprmn}	feed elements yielded by a PAST per soil type per pasture type per stocking rate per period per nutrition type	Mcal year^{-1}; kg year^{-1}
n_{fn}	feed elements yielded by a FAST per supplementary feed type per nutrition type	do
n_{hnm}	feed elements required by an APST per herd type per nutrition type per period	do
s_{spr}	stocking rate per soil type per pasture type per stocking rate	animal units ha^{-1}
h_h	herd size per herd type	animal units herd^{-1}
b_{zs}	land availability per farm type per land unit (RHS)[6]	ha year^{-1}

[1] OBJ: objective function coefficient

[2] LUST: variable X_{zslt}, see Table 3

[3] APST: variable A_{zh}, see Table 3

[4] PAST: variable P_{zspr}, see Table 3

[5] FAST: variable F_{zfm}, see Table 3

[6] RHS: right hand side coefficient

Table 4 Part of coefficients in NAZ model, continuation

coeffi-cients	description	units of measurement
l_{slt}	annuity use of labor by a LUST[1]	days ha^{-1}
l_h	annuity use of labor by an APST[2]	do
l_{spr}	annuity use of labor by a PAST[3]	do
l_f	annuity use of labor by a FAST[4]	do
o_o	annuity use of labor related to each segment limit of the total labor supply function	days year^{-1}
a_ζ	(annuity of) agricultural labor force availability (RHS)[5]	days year^{-1}
δ_{slte}	sustainability indicator of LUSTs per indicator type	kg ha^{-1}; index ha^{-1}
δ_{spre}	sustainability indicator of PASTs per indicator type	kg ha^{-1}; index ha^{-1}
d_{zse}	limit to sustainability indicator per sub-region per soil type per indicator type (RHS)	kg year^{-1}; index year^{-1}
d_{ze}	limit to sustainability indicator per sub-region per indicator type (RHS)	kg year^{-1}; index year^{-1}
d_{se}	limit to sustainability indicator per soil type per indicator type (RHS)	kg year^{-1}; index year^{-1}
d_e	limit to sustainability indicator per indicator type for whole NAZ (RHS)	kg year^{-1}; index year^{-1}

[1] LUST: variable X_{zslt}, see Table 3

[2] APST: variable A_{zh}, see Table 3

[3] PAST: variable P_{zspr}, see Table 3

[4] FAST: variable F_{zfm}, see Table 3

[5] RHS: right hand side coefficient 3

6. Results of policy simulations

The Costa Rican government has called for the execution of research that explicitly analyzes, for a range of policy options, the trade-offs between socio-economic and environmental goals (SEPSA, 1997). In this context, we will demonstrate the capabilities of the SOLUS methodology through the evaluation of four scenarios related to policy issues as exposed in section 4: *taxing biocides to reduce environmental contamination*, *maintaining natural forests*, *reducing domestic public debt resulting in lower interest rates*, and *upgrading the road infrastructure*. In addition, the effects of expected *increases in real wage levels* are analyzed as well. Whereas the first four scenarios can be considered to represent specific agricultural and/or economic policies, the fifth scenario is based on the likely effects of continuous increases in per capita income. The effects of each policy are studied by comparing the results *with* the policy with the results *without* such a policy, *i.e.* the *base* run.

However before presenting these analyses, we will compare land use as it would be, according to the model, if *only* the present technologies in crops, pastures and animal husbandry systems are available (*present technology* run), with a situation in which *also* alternative, improved technologies are available, *i.e.* the *base* run. In this way the effects of improved technologies on income, employment, land use and environmental indicators can be assessed.

6.1 Land use under present technology compared to the base run land use

Technological progress, essentially producing more with the same or less resources (land, labor), has an important effect on economic surplus, employment, land use, and environmental indicators. This can be observed in Table 5. Economic surplus (value of the objective function) increases with 21.4% between the present technology and the improved technology scenarios. Overall land productivity increases with the same percentage (the same area is used), while labor productivity increases with 26.7% (higher surplus, using less labor). As a consequence, employment decreases with 4.2%. Both environmental indicators are more favorable in the *base* run than in the *present technology* run. The amount of active ingredients (BIOA) decreases with 33%, while the Biocide Indicator (BIOI) decreases with 16%. Thus, improved technologies results in a win-win situation, i.e., higher economic surplus and less environmental contamination.

In the next sections, comparisons to assess the effects of a policy or a likely development are made with the *base* run, thus assuming the availability of improved technologies.

Table 5 Assessing impact of technological change: *present technology* versus technology in *base* run

		SCENARIOS	
	Units	BASE	PRESENT
Objective	$\$ * 10^6$	267.624	220.495
Labor use	days * 10^6	8.661	9.039
BIOA	Kg * 10^6	1.935	2.905
BIOI	10^6	84.103	99.990
Crops	Ha	61,218	76,626
Pastures	Ha	189,792	174,384
- natural	Ha	150,624	174,384
- grass legume	Ha	39,168	0
Animal, breeding	Animal Units	252,548	197,725
Animals, fattening	Animal Units	138,339	115,494
Crops			
Banana – area	Ha	31,622	42,865
Banana – production	Ton	2,064,186	1,851,696
Pineapple – area	Ha	2,257	2,794
Pineapple – production	Ton	194,252	196,820
Palm heart – area	Ha	7,667	11,179
Palm heart – production	Ton	82,229	60,128
Plantain – area	Ha	1,884	1,937
Plantain – production	Ton	35,299	37,075
Cassava – area	Ha	17,105	17,683
Cassava – production	Ton	87,235	90,186

BIOA Amount (kg) of active ingredient in all biocides

BIOI Biocide Indicator (index of environmental effects of all biocides together)

6.2 *Taxing biocides*

Regulation and control of agricultural input use has been identified as an important policy option for the government to reduce certain negative externalities of agricultural production (SEPSA, 1997). The structural changes of the Costa Rican agricultural sector over the past decade have clear links to the increasing trend in biocide use. In Costa Rica, biocide policies have traditionally consisted of legislative measures without considering the potential effects of economic instruments (Agne, 1996). It can be expected that the taxing of an input which is currently not taxed[7] but has clear negative externalities (such as environmental contamination and human health damage caused by biocide use; Jansen *et al.*, 1998) will lead to a diminished use of this input. Such a tax can be implemented in a variety of ways and at different levels. In this paper we distinguish between a flat tax and a progressive tax. The latter is related to the environmental damage caused by a specific biocide. Such damage, in turn, is related to both the toxicity of the biocide as well as to its persistence in the environment. Both these aspects are taken into

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[7] Agrochemicals as well as agricultural equipment are tax exempt since 1992 (Agne, 1996).

account in the Biocide Indicator (BIOI)[8]. Taxing all biocides at a uniform rate of 100% leads to a reduction in the use of biocides in terms of active ingredients (BIOA) of 13% relative to the base scenario, while the BIOI is reduced by only 4% (Table 6). However, the economic surplus (objective function value) is reduced with nearly 19%. Thus, a relatively modest environmental gain is obtained at high economic costs. In contrast, in a progressive tax regime where different tax rates are applied to three categories of biocides depending on their degree of toxicity (*i.e.*, slightly, medium and very toxic) results in a much larger reduction of the BIOI while at the same time preserving more of the economic surplus. For example, applying taxes of 20%, 50% and 200% (Table 6, Tax System A) to the categories of slightly, medium and very toxic biocides, respectively, leads to a reduction in the economic surplus of a 4%, while reducing the BIOI by over 80%. When tax rates are reduced to 10%, 20% and 150% (Tax System B), respectively for the three categories of biocides, economic surplus decreases by just 2% with the same environmental improvement. On the other hand, limiting the tax on biocides in the very toxic category to 100% (Tax System C) does not result in a significant environmental gain.

Table 6 Effects of different types and levels of a tax on biocide use

Type of biocide	Units	Base	Flat tax	Tax system A	Tax system B	Tax system C
Slightly toxic		0%	100%	20%	20%	10%
Medium toxic		0%	100%	50%	50%	30%
Very toxic		0%	100%	200%	100%	150%
		absolute value	% change	% change	% change	% change
Objective	$ * 10^6	267.624	-18.69	-4.16	-4.10	-2.23
BIOA	Kg * 10^6	1.681	-13.14	-3.90	-3.19	-3.81
BIOI	10^6	15.001	-3.98	-81.94	-1.50	-81.89

BIOA	Amount (kg) of active ingredient in all biocides
BIOI	Biocide Indicator (index of environmental effects of all biocides together)

It can be concluded that even though a flat tax results in the highest reduction in the absolute quantities of biocides applied, such a tax is ineffective when it comes to protecting the environment. At the same time, a flat tax is not efficient in the sense that it leads to large decreases in economic surplus. In contrast, a biocide tax differentiated in relation to the degree of toxicity of each biocide can indeed reduce environmental damage to a substantial degree at relatively low economic cost. A comparable conclusion is reached in Jansen *et al.* (1997a) for the Guácimo country in Costa Rica. It should be kept in mind that rather large differences in tax rates were evaluated; for a more precise policy advice a more refined

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[8] Elsewhere called the Biocide Environmental Impact Indicator (BEII; Jansen *et al.*, 1997a) or the Pesticide Environmental Impact Indicator (PEII; Bouman *et al.*, 1998d).

analysis would be warranted, involving a search for an optimal tax policy.

6.3 Conservation of natural forests

Agricultural policy in Costa Rica puts increasing emphasis on environmental protection (SEPSA, 1997). Consequently, the identification of efficient instruments to realize protection of natural resources at minimal economic cost becomes increasingly important. Currently, the government of Costa Rica has a policy to stimulate land owners to keep part of their property under natural forest. In return for not cutting down the forest, as of 1997 a landowner can obtain a subsidy of ¢ 10,000 per ha of forest per year, initially for a period of five years. Taking into account an obligatory first year cost of ¢ 3,000 for an officially approved forest management plan, this means an annuity of US$ 40 per year at the 1997 exchange rate of $ 1 = ¢ 232.

Table 7 Maintaining or creating 'natural' forests by valuing non-timber products & services through a subsidy per ha

			All-land			
	Units		No non-timber value to forest	$ 111 per ha subsidy	$ 222 per ha subsidy	$ 333 per ha subsidy
			Area with natural forest			
Soil type		Available land				
-SFW	Ha	118,434	0	0	0	0
-SFP	Ha	135,969	0	0	62,573	122,373
-SIW	Ha	85,708	0	0	56,363	77,137
Sub-total	Ha	340,111	0	0	118,936	199,509
Objective	$ * 10^6		275.8	275.8	276.1	277.9

SFW	Soil Fertile Well-drained
SFP	Soil Fertile Poorly-drained
SIW	Soil Infertile Well-drained

To analyze the effect of a subsidization policy on regional land use, premiums were allocated to the land use type *natural forest*. Natural forest can be exploited in a sustainable way, yielding about 0.6 m^3 of wood per ha per year, which means an annual return of about $ 16 per ha. The linear programming model was run with all the available land in the NAZ (340,000 ha) suitable for agricultural (crops, pastures and forests) use, thus including the protected (*e.g.* national parks) and semi-protected (*e.g.* buffer zones, forest reserves) areas. In the base year of the model, 1996, a subsidy of $ 111 per ha of forest per year (¢ 20,000 converted at the average 1994-96 exchange rate of US$ 1 = ¢ 181), is not sufficient to induce landowners to maintain natural forests (Table 7). On the other hand, subsidies of $ 122 and $ 133 per ha would lead to forest areas of about 120,000 ha and 200,000 ha, respectively, which should be compared to the about 84,000 ha at present with primary or secondary forest in the area suitable for agriculture. In case of such subsidies, a large part of the land used for pastures in the base scenario is converted to natural forests, while the cropped area remains virtually constant.

Even though a subsidy of $ 111 per ha would raise the annual return of natural forest to US$ 117 per ha, this is still lower than the shadow price of land in all sub-regions and for each soil type. In case of a subsidy of $ 122, however, returns of natural forest exceed the shadow prices of the land belonging to the soil types SFP and SIW in most sub-regions. On the other hand, land of soil type SFW has shadow prices between $ 188 and $ 204 per ha (depending on the sub-region) and a subsidy would have to exceed US$ 172 per ha per year for natural forest land to become an economically attractive option. Soil types SFP and SIW are mostly used for pasture, while SFW land is mostly used for crops. This lends support to the hypothesis that pasture and natural forest are competing land use types for the marginal land areas.

Table 8 Using semi-protected and protected areas for agriculture

Scenario	Objective	Increase of objective	% change objective	Area	Increase of area	% change area	Average returns	Incremental returns
	$\$ * 10^6$	$\$ * 10^6$		Ha	Ha		$ per ha	$ per ha
Base	267.4			278,900			960	
Base & semi-protected	274.0	6.6	2.5	327,614	48,714	17.5	837	134
All land	275.8	1.7	0.6	340,111	12,497	3.8	811	131

The above analysis to determine the optimal level of a natural forest subsidy can be extended by analyzing land use at the margin from a different perspective. Suppose there does not exist a subsidy for natural forests. In the base scenario only land outside the protected and semi-protected areas is considered (279,000 ha). Extending the availability of land with the semi-protected areas only (49,000 ha), or with both the semi-protected and the protected areas (61,000 ha), respectively, gives an indication of the incremental increase in economic surplus *if* these areas could be used for agricultural purposes. Table 8 indicates that the increments in economic surplus are not substantial. Extending the base case area with the semi-protected areas (17.5% more land) leads to a rather marginal (2.5%) increase in economic surplus. Average yearly returns per ha decrease from $ 960 to $ 837. The incremental economic surplus of the semi-protected areas is only $ 134 per ha. Similarly, extending the base and semi-protected area case with the land of the protected areas (another 3.8% additional land) results in a further 0.6% increase in the economic surplus. Average returns per ha drop to $ 811 per year, while the incremental returns of the protected areas is $ 131 per ha. A comparison of land use patterns in each of the three above cases reveals that all extra land is used for pasture. This is a consequence of the limited demand for crop products at sufficiently remunerative prices, incorporated in the model through the downward sloping demand functions. Obviously, the incremental increases in economic surplus by extending the pasture area are consistent with the earlier analysis regarding the minimum effective subsidy for natural forests preservation.

6.4 Effects of lower interest rates on income, employment and land use

Costa Rica is currently undertaking efforts to reduce the internal (public sector) debt, mainly through the (intended) sale of a number of public enterprises to private investors. Since a decrease in the size of the internal debt would imply lower debt servicing payments and a corresponding decrease in the demand for capital by the government, interest rates can be expected to come down. To simulate the effect of a reduction in the real interest rate on land use in the NAZ, the model was run with a discount rate of 3% (instead of 7% in the base scenario). The effect of a such a lower discount rate on land use turned out to be rather limited (Table 9). The area under crops increases slightly, at the expense of pasture area. Within the area under pastures, there occurs a shift away from unfertilized natural(ized) species towards an unfertilized improved pasture-legume combination (*B. brachiaria* with *arachis pintoi)*. Since this pasture-legume combination requires a substantial initial investment of about US$ 400 per ha (Jansen *et al.*, 1997b), such an investment becomes more profitable at lower discount rates because of lower capital costs. Not surprisingly, economic surplus (*i.e.*, the value of the objective function) increases as well, mainly because most benefits occur later than costs and consequently suffer less from discounting. An explanation for the modest changes in land use that result from a more than 50% decrease in the discount rate may be that the linear programming model, being an optimization model, compares the relative profitability of each alternative land use system, thereby taking into account all constraints, including the market constraints implicitly imposed by means of downward sloping demand functions. Since lowering the discount rate from 7% to 3% changes the relative profitability of each activity only marginally, while the market constraints remain the same, land use is only slightly affected.

Table 9 Discount rate and land use

	Units	Discount rate 3%	Base (discount rate 7%)
Objective	\$ * 10^6	281.389	267.624
Labor	Days * 10^6	8.594	8.661
Crops	Ha	62,737	61,218
-pineapple	Ha	2,877	2,757
-palm heart	Ha	7,980	7,662
-banana	Ha	31,921	31,622
-plantain	Ha	1,987	1,884
-cassava	Ha	17,776	17,104
Pastures	Ha	188,273	189,792
- natural pasture	Ha	148,687	150,624
- grass-legume mixture	Ha	39,586	39,167
Animals			
-breeding, low growth	Animal Units	250,712	252,548
-fattening, low growth	Animal Units	137,333	138,339

6.5 Increasing wages

International development banks expect a GDP growth in Cost Rica of between 4.5 and 5% per year for the next five years. Given an expected population growth of 2% per year, this translates into a 2.5 to 3% annual increase of per capita GDP, similar to the average per capita GNP growth of 2.8% realized between 1985 and 1995. Assuming a continuation of such a per capita GNP growth in the future (*i.e.*, beyond the year 2003), it is likely that real wages will increase concurrently. A 2.8% increase per year during 20 years means a total wage increase of 74%.

To simulate the potential impact of real wage increases on land use, three scenarios were evaluated, with total wage increases of 50%, 75% and 100%, respectively. A 75% aggregate wage increase can be expected on the basis of a continuation of current and past trends; the remaining two scenarios were evaluated to explore the sensitivity of the model to wage increases. A real wage increase of 75% results in less crop land and more land under pasture (Table 10). Wage increases of 50 and 100% result in similar type of land use changes. The principal reason for these results is that crops use relatively more labor than pastures, as also indicated by a decrease in the number of animal units per ha which drops from 2.06 to 1.87, making animal husbandry less labor intensive.

Table 10 Increasing real wages: effects on economic surplus, employment and land use

Scenario Units	Objective $\$ * 10^{6}$	Labor NAZ Days * 10^{6}	Labor income $\$ * 10^{6}$	LUSTs Ha	PASTs Ha	Animals: breeding Animal Unit	Animals: fattening Animal Unit
Base[1]	267.624	8.661	76.576	61,218	189,792	252,458	138,339
Wage + 50%	232.171	7.595	100.669	54,941	196,069	232,952	128,152
Wage + 75%	215.842	7.259	112.311	43,689	207,320	250,283	137,098
Wage + 100%	200.193	7.017	124.076	42,031	208,979	252,659	138,400

[1] Wage in base run is $ 8.84 per day.

Not surprisingly, labor use in the agricultural sector of the NAZ diminishes with increasing real wage rates. In a growing economy labor can be expected to be increasingly employed in the non-agricultural sectors of the economy. Economic surplus also decreases with increasing real wages, as wages constitute a cost component in the model. On the other hand, wages represent also income to laborers. Thus, the sum of the economic surplus and total wage income (number of labor days times wage) better reflects the economic gains resulting from land use in the NAZ to Costa Rican society as a whole. In the base scenario this sum is $ 344 million, while at a 75% wage increase this sum is $ 333 million. Thus, as the economic surplus created in the agricultural sector in the NAZ decreases with 13.2% (from $ 267 million to $ 232 million) as a result of a 75% increase in the real wage rate, the sum of economic surplus and labor income decreases with only 3.3%.

6.6 Improvement of road infrastructure

The zonification of the NAZ in the linear programming model is based on transport costs resulting from the existing road infrastructure (Figure 2). Road improvements lower transportation costs which in turn can be expected to influence land use in the different sub-regions of the NAZ. However, changes in the road infrastructure require new GIS overlays resulting in an adapted zonification.

An example of an improved road system with a new zonification is depicted in Figure 3. Two categories of roads are distinguished, with or without bitumen. The first category is extended from 300 km of roads to 550 km, thereby reducing the roads in the second category from 2,500 km to 2,250 km. Model simulations indicate that such an improvement has no significant impact on land use. Economic surplus increases with $ 88,000, or a mere 0.03% relative to the base scenario (Table 11). As the costs of upgrading roads of the second to the first category are about $ 55,000 per km, such an upgrading clearly can not be justified by the agricultural surplus alone.

Table 11 Effects of upgrading roads on economic surplus generated by agriculture

Scenario	Objective $\$ * 10^6$	Change in objective $\$ * 10^6$	% change objective
Base	267.624		
Upgrading infrastructure	267.713	0.088	0.033

The very modest influence of a reduction in transportation costs on land use in the NAZ can be explained by the size of the transport costs relative to total production costs. Transport costs in the base scenario are $ 18 million, while the total costs for current inputs are $ 475 million. At the same time, improving the road system lowers transportation costs for all crops, *i.e.*, does not significantly influence the relative profitability of the different land use types. Even though land use types do differ in their relative profitability, the most profitable types were already selected in the base scenario, given existing land, labor and market restrictions. A reduction of transportation costs that is uniform across land use types will therefore hardly change the optimal land use pattern (*ceteris paribus* the land, labor and market restrictions).

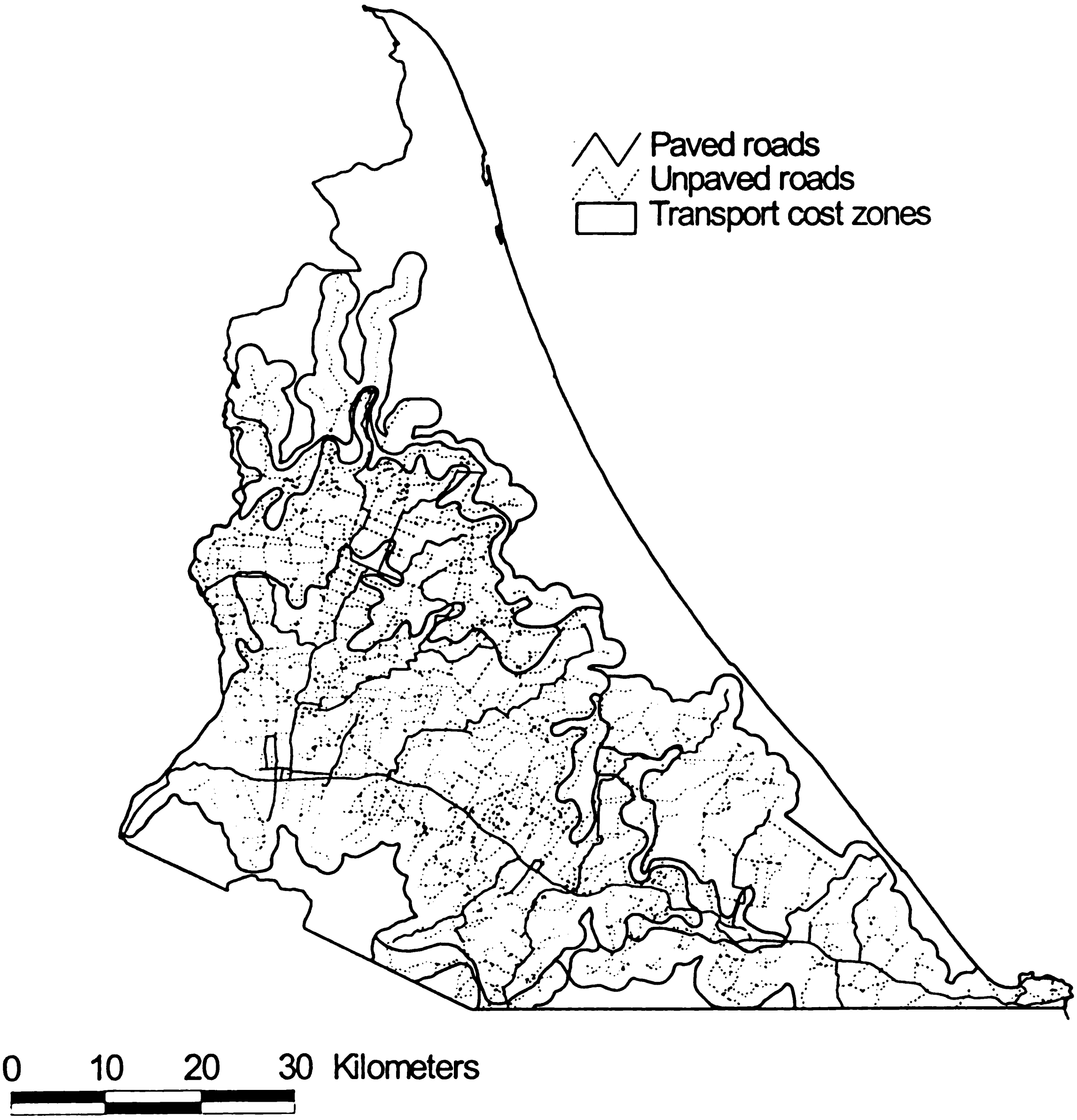

Figure 3 Map of Northern Atlantic Zone in Costa Rica with 12 sub-regions and *improved* system of roads

7 Conclusions

The REALM bio-economic model, as part of the SOLUS methodology, maximizes the sum of the producer and consumer surpluses by selecting among a large number of technological options for crop, pasture and animal husbandry activities, while at the same time taking into account resource and market constraints, as well as environmental restrictions. In that way, detailed biophysical knowledge of a multitude of land use options is combined with aggregate economic behavior of producers and consumers, as expressed in supply and demand functions in multiple markets.

REALM can be characterized as a – linear programming – optimization model of the agricultural sector of the NAZ region. Next to variables for land use activities, each with its own input and output coefficients, based on separate technical coefficient generators for crop and livestock activities, it contains production and labor-use variables. Regional resource constraints are formulated for land and labor resources. Environmental indicators are included and related to environmental restrictions. As the NAZ region is a 'large' region, the supply originating from this region is often an important part of the total supply to the domestic market. Therefore, the production variables are related to downward sloping demand functions for most products for the domestic market. In this way, product prices are no longer fixed, but become endogenous. In addition, for a few products that are exported to foreign markets in which the Costa Rican supply is a considerable part of the total supply, a comparable construction is built into the model. With regard to the labor market, it is assumed that labor can be hired at a fixed wage up to the quantity of regional labor at present working in the agricultural sector of the NAZ. Beyond this point, labor can be hired away from other sectors/regions at increasingly higher wages, making wages endogenous too. In the product markets as well as in the labor market, care is taken to include the feature that NAZ supply or demand is only part of the total supply or demand on each of these markets. Therefore, supply or demand of other regions is also taken into account. Finally, because of the size of the NAZ, the region is sub-divided into 12 sub-regions to be able to take into account transport costs for agricultural, livestock and forest products, as well as travel-related transaction costs for labor living in one sub-region, but working in another.

Land use policies at either the national or regional level ideally should be based on a simultaneous evaluation of the socio-economic and environmental implications of both actual and potential technological options for land use. The REALM model within the SOLUS methodology provides a useful tool for such an evaluation under the particular conditions of the NAZ region at the end of the 1990s. Policy decisions aiming at an improved land use in the medium and long term can be analyzed with such an instrument.

Important issues with regard to economic and agricultural policies relevant for the NAZ are related to the impact of technological change, the desire to reduce biocide related pollution to avoid negative effects for human health and the environment, the policy objective to maintain natural forests (ecological balance, global warming, tourism), the effects of reduced interest rates, and the possibility to stimulate economic development through upgrading the road infrastructure. Another important question is what kind of effects on land use can be expected from continuous real wage increases, as a consequence of general economic development. REALM has been shown to be a useful instrument for the assessment of each of these issues, and as such is able to better inform policy makers.

The following conclusions can be drawn, based on the policy simulations described in the previous sections.

1. Changes in land use technologies can bring simultaneous economic as well as environmental gains, thus providing a 'win-win' situation.
2. A progressive tax on biocides related to their toxicity, aiming at a reduced use, proved to be more efficient than a flat tax; an 'optimal' tax policy could be analyzed with the help of REALM.
3. Subsidizing natural forests land use - implying that society at large recognizes that the value of those forests exceeds potential timber revenues - could help to maintaining existing natural forest areas or creating new ones; at the same time, extending the agricultural area (crops and pastures) into the existing (semi-)protected areas only brings marginal economic benefits, mainly because these protected areas would be converted to pastures.
4. Lower discount rates as a consequence of a reduced public debt has only limited effects on land use; the area under crops would increase somewhat at the expense of pastures, and the remaining pastures would have higher stocking rates. Crops, and pasture types permitting higher stocking rates, require higher investment than natural pastures, and such investments are more attractive at lower discount rates. However, as markets for crop products are limited, producing more at lower prices is not remunerative. The only way to substantially increase regional economic surplus – not explored in the present version of REALM – is to look for new markets for existing products (*e.g.* bananas in China) or to introduce new crops with promising market prospects. However, whether such an agricultural expansion can be obtained in a sustainable and environmentally friendly way remains an open question that could be assessed using REALM as well.
5. Expected higher wages as a consequence of overall economic development would lead to a reduction of the area with crops and an expansion of pastures. Not surprisingly, labor intensive activities are substituted by labor extensive ones. If wage increases in Costa Rica would exceed wage increases in competing production countries, Costa Rica may gradually loose its competitive advantage for crops like bananas, plantain, palm heart, cassava and pineapple.
6. Improving the existing road infrastructure hardly increases economic surplus. Given the existing

marketing possibilities for crops like bananas, plantain, palm heart, cassava and pineapple, hardly more use will be made of the improved roads to transport these products; instead roads will be used mostly to transport more live animals, with relatively low profits. As with conclusion 4, these results might have been different if other crops with good marketing prospects would have been included into the model.

REALM is a suitable tool for policy studies given the place and time for which it was designed: the Northern Atlantic Zone of Costa Rica at the closing of the 20th century. Notwithstanding, it is important to recognize its limitations as well. Apart from some methodological issues as outlined in Sections 2 and 5, REALM in its current version is limited with regard to the number of existing or potential land uses included. Possibilities that could be studied in the future are rice (for which a potentially large world market exists), crops like papaya or sour sop (for which market possibilities are more limited), and tree plantations (e.g., teak). For each of these cases bio-physical production possibilities in the Northern Atlantic Zone of Costa Rica are good. REALM, as part of the SOLUS methodology, seems a useful tool to explore aspects of sustainability and environmental impacts for each of these potential new land use types in addition to an assessment of market possibilities.

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Appendix 1. Listing of GAMS program REALM

```
$TITLE  A LAND USE MODEL WITH SUB-REGIONS OF THE NORTHERN ATLANTIC ZONE OF COSTA RICA

$OFFUPPER

* REALM (Regional Economic and Agricultural Land-use Model)
* Authors: Robert A. Schipper & Bas A.M. Bouman, 15 April 1998
* Version 4.0
*
* date 4 september 1998, FILE: REALM40.GMS


*=================================================================*
*                1. MAIN MODEL REALM                              *
*=================================================================*

* ----------------------------------------------------------------
* 1.1 SET DECLARATIONS
* ----------------------------------------------------------------

SETS
  PA                 product abbreviations
  R                  "sub-regions; in case of labour, `to' regions, demanding labour"
  S                  soil types
  C(PA)              land use type: crops
  TL                 "technology level: fertiliser, biocide, herbicide and mecanisation"
  TY                 crop cycle: number of years a crop stands in the field
  CTY(PA,TY)         possible crop  crop cycle combination
  LP(S,PA,TL,TY)     "permissible soil, crop, technology & crop cycle combinations (LUSTs)"
  LM(S,PA,TL,TY)     "mechanised LUSTs"
  T(TL,TY)           technology: combination of technology level and crop cycle
  F                  feed types supplementary feed
  P                  pasture types & technology
  SR                 stocking rates
  H                  herd types & sizes
  PP(S,P,SR)         "permissible soil, pasture & stocking rate combinations"
  HN                 nutrient & energy types required by herds (from grasses and feed)
  HP(PA)             type of herd products
  Q                  quality or type of product
  CQ(PA,Q)           allowable crop products
  HPQ(PA,Q)          allowable herd products
  PD(PA)             products for domestic market
  PD1(PA)            products for domestic market without market constraint
  PD2(PA)            products for domestic market with downward sloping demand function
  PX(PA)             products for export market
  PX1(PA)            products for export market without market constraint
  PX2(PA)            products for export market with downward sloping demand function
  QD(Q)              non-exportable quality or type of product
  QD1(Q)             non-exportable quality or type of product without market contraint
  QD2(Q)             non-exportable quality or type of product with downward sloping demand function
  QX(Q)              exportable quality or type of product
  PDQD(PA,Q)         permissible product and quality or type combinations for domestic market
  PD2QD2(PA,Q)       permissible product and quality or type combinations for domestic market
*                     with downward sloping demand functions
  M                  periods: months of a year
  SE                 seasons in year
  SU                 sustainability indicators
  D                  downward sloping product demand function segment limits
  LS                 upward sloping labour supply function segment limits
  LS1(LS)            sub-set of upward sloping labour supply function segmetn limits
  Y                  years of `planning' period
;

ALIAS (R,RR)
;
* "sub-regions; in case of labour, `from' regions, supplying labour"
```

```
* --------------------------------------------------------------------------
* 1.2 SET DEFINITIONS
* --------------------------------------------------------------------------

* Feed supplements
$INCLUDE C:\USR\REALM\ECONOM\INCPASTO\SET_F.TXT
$ ONTEXT
A selection is offered of the following feed supplement types
  F         /
             MOL    Molasse of cana
             BAN    Green rejected banana
             CN1    Gallinaz engorde intens
             CN2    Gallinaz engorde
             CN3    Gallinaz leche bajura
             CN4    Gallinaz leche especial
             P20    P20 phosphorus
             MGO    MG micronutrients
             CAN    Cogollo de cana
            /
$ OFFTEXT
* Pasture types
$ INCLUDE C:\USR\REALM\ECONOM\INCPASTO\SET_P.TXT
$ ONTEXT
   Elements of set P are formed through a coding system consisting
   of a letter and a number of two digits with:
   1. a letter indicating grass type:
   B = Brachiaria brizantha (fertilized)
   E = Estrella (Cynodon nlemfuensis) (fertilized)
   T = Tanner (Brachiaria radicans) (fertilized)
   I = Grass-legume mixture, B.brachiaria/aracis pintoi (unfertilized)
   N = Mixture of natural(ized) species (unfertilized)
   Y = dummy1, Z = dummy2
   2. A 2-digit code indicating the relative fertilisation level
   for the fertilized pastures B, E and T: 20 = low (0%), 40 = high (100%)
   and 'not indicating annything' for the non-fertilzed N and I.
 Weeds in the B, E, T and N pastures are controlled by hand and by applying
 herbicides; weeds in I are only controlled by hand.
$OFFTEXT
* Stocking rates
$ INCLUDE C:\USR\REALM\ECONOM\INCPASTO\SET_SR.TXT
$ ONTEXT
  SET     SR      Stocking rates
         /     R11      stocking rate    1.000  au-ha
               R12      stocking rate    1.250  au-ha
               R13      stocking rate    1.500  au-ha
               R14      stocking rate    1.750  au-ha
               R15      stocking rate    2.000  au-ha
               R16      stocking rate    2.250  au-ha
               R17      stocking rate    2.500  au-ha
               R18      stocking rate    2.750  au-ha
               R19      stocking rate    3.000  au-ha
               R20      stocking rate    3.250  au-ha
               R21      stocking rate    3.500  au-ha
               R22      stocking rate    3.750  au-ha
               R23      stocking rate    4.000  au-ha
               R24      stocking rate    4.250  au-ha
               R25      stocking rate    4.500  au-ha
               R26      stocking rate    4.750  au-ha
               R27      stocking rate    5.000  au-ha
               R28      stocking rate    5.250  au-ha
               R29      stocking rate    5.500  au-ha
               R30      stocking rate    5.750  au-ha
               R31      stocking rate    6.000  au-ha  / ;
$OFFTEXT
* Herd types
$ INCLUDE C:\USR\REALM\ECONOM\INCPASTO\SET_H.TXT
$ ONTEXT
Explanation of herd types. The code consists of two letters and a 3-digit number.
The letters indicate herd type:
HB = breeding, low growth rate (0.65 kg/hd/d in first year)
HX = breeding, intermediate growth rate (0.8 kg/hd/d in first year)
HY = breeding, intermediate  growth rate (0.9 kg/hd/d in first year)
*HZ = breeding, high growth rate (1.0 kg/hd/d in first year)
HF = fattening, low growth rate (0.45 kg/hd/d)
HR = fattening, intermediate growth rate (0.6 kg/hd/d)
HS = fattening, intermediate  growth rate (0.7 kg/hd/d)
HT = fattening, intermediate  growth rate (0.8 kg/hd/d)
HU = fattening, intermediate  growth rate (0.9 kg/hd/d)
*HV = fattening, high growth rate (1.0 kg/hd/d)
The 3 digits indicate size of the herd units (minus 100):
150 = 50 Animal Units
```

```
$OFFTEXT

SETS
  PA        /AC, AM, BG, GA, SN, OS, MA, MB, ME, PV, TG, ZM, ZC,
             LWCY, LWCO, LWEY, LWDY, MLK/
  R         /
*R000  outside the Northern Altlantic Zone (NAZ)
             R111  sub-region 111
             R112  sub-region 112
             R121  sub-region 121
             R211  sub-region 211
             R212  sub-region 212
             R221  sub-region 221
             R2221 sub-region 2221 (222a)
             R2222 sub-region 2222 (222b)
             R2223 sub-region 2223 (222c)
             R9991 sub-region 20 (a0) no roads
             R9992 sub-region 30 (b0) no roads
             R9993 sub-region 40 (c0) no roads/
* the sub-regions are coded as an R together with three or four digits,
* meaning (except in case all digits are zero's, indicating `outside NAZ'):
* 1st digit, transport costs crops to intersection to San Jose
* just before Braulio:
* 1 = 1, 2 or 3  C./kg; 2 = 4, 5 or 6 C./kg; 9 = no roads
* 2nd digit, transport cost live animals to intersection to San Jose.
* just before Braulio:
* 1 = 200, 500 or 800 C./AU; 2 = 1100 or 1400 C./AU; 9 = no roads.
* 3rd digit, transport costs crops to Limon:
* 1 = 1, 2, 3 or 4 C./kg; 2 = 5, 6, 7, 8 or 9 C./kg; 9 = no roads.
* 4th digit, if necessary, a geographic sub-division.
  S         /SFP soil fertile poorly drained
             SFW soil fertile well drained
             SIW soil infertile well drained/
  C(PA)     /AC  pineapple (Ananas comosus) for export market
             AM  pineapple (Ananas comosus) for domestic market
             BG  palm heart (Bactris gasipaes)
             GA  melina (Gmelina arborea)
             SN  natural forest (Selva natural)
             OS  rice (Oryza sativa)
             MA  banana (Musa cvs (AAA group))
             MB  plantain (Musa cvs (AAB group))
             ME  cassave (Manihot esculenta)
             PV  (black) beans (Phaseolus vulgaris)
             TG  ECONOM (Tectona grandes)
             ZM  maize (Zea mays): corn
             ZC  maize (Zea mays): cobs/
  TL        /F0LLL, F0LLH, F0LHL, F0LHH, F0HLL, F0HLH, F0HHL, F0HHH
             F1LLL, F1LLH, F1LHL, F1LHH, F1HLL, F1HLH, F1HHL, F1HHH
             F2LLL, F2LLH, F2LHL, F2LHH, F2HLL, F2HLH, F2HHL, F2HHH
             F3LLL, F3LLH, F3LHL, F3LHH, F3HLL, F3HLH, F3HHL, F3HHH
             F4LLL, F4LLH, F4LHL, F4LHH, F4HLL, F4HLH, F4HHL, F4HHH
             F5LLL, F5LLH, F5LHL, F5LHH, F5HLL, F5HLH, F5HHL, F5HHH
             F6LLL, F6LLH, F6LHL, F6LHH, F6HLL, F6HLH, F6HHL, F6HHH
             F7LLL, F7LLH, F7LHL, F7LHH, F7HLL, F7HLH, F7HHL, F7HHH
             F8LLL, F8LLH, F8LHL, F8LHH, F8HLL, F8HLH, F8HHL, F8HHH
             F9LLL, F9LLH, F9LHL, F9LHH, F9HLL, F9HLH, F9HHL, F9HHH/
*   elements of set TL are formed through a coding system of one letter with
*   with a number in combination with three other letters:
*   1st letter with number indicates fertilisation level
*   F0 = `soil nutrient depleting LUST'
*   F1 to F9 indicate `soil nutrient non-depleting LUSTs with
*   F1 = lowest fertiliser level, and F9 = highest fertiliser level'
*   for example:
*   F1 = `soil nutrient non-depleting LUST; lowest fertiliser level'
*   2nd letter: L = low biocide,       H = high biocide application
*   3rd letter: L = low herbicide,     H = high herbicide application
*   4th letter: L = low mechanisation, H = high mechanisation level
  TY        /01 one year crop cycle (bean cassava maize pineapple)
             02 two year crop cycle (pineapple)
             10 ten year crop cycle (banana  palm heart  plantain)
             12 12 year tree cycle for melina
             14 14 year tree cycle for melina
             15 15 year crop cycle (banana  palm heart  plantain)
             20 20 year crop cycle (natural forest)
             25 25 year tree cycle for ECONOM/
  CTY(PA,TY) /AC.01, AC.02,
              AM.01, AM.02,
              BG.10, BG.15,
              GA.12, GA.14
              SN.20,
              OS.01,
```

```
              MA.10, MA.15,
              MB.10, MB.15,
              ME.01,
              PV.01,
              TG.25
              ZM.01
              ZC.01/
  LP(S,PA,TL,TY)
$INCLUDE C:\USR\REALM\ECONOM\TCCROP\LUST_COM.PRN
  LM(S,PA,TL,TY)
$INCLUDE C:\USR\REALM\ECONOM\TCCROP\MECH_COM.PRN
  PP(S,P,SR)
$INCLUDE C:\USR\REALM\ECONOM\TCPASTO\GRASCOM.PRN
  HN         /HME  metabolisable energy (ME) provided by pastures & feed
             HCP   crude protein provided by pastures & feed
             HP    phosphorus provided by pastures & feed/
  HP(PA)     /LWCY live weight of all sold male & female calves of breeding herd
             LWCO live weight of all sold old cows of breeding & double purpose herds
             LWEY live weight of all sold male calves of fattening herd
             LWDY live weight of sold male & female calves double purpose herd
             MLK  milk/
  Q          /EXP exportable quality
             DOM domestic quality or type 1
             REF refuse/
  CQ(PA,Q)   /AC.EXP, AC.REF,
             AM.DOM, AM.REF,
             BG.EXP,
             GA.EXP,
             SN.EXP,
             OS.EXP,
             MA.EXP, MA.REF,
             MB.EXP, MB.DOM,
             ME.EXP, ME.DOM, ME.REF,
             PV.EXP,
             TG.EXP, TG.REF,
             ZM.EXP,
             ZC.DOM/
   HPQ(PA,Q) /LWCY.EXP,
             LWCO.EXP,
             LWEY.EXP,
             LWDY.EXP,
             MLK.EXP/
   PD(PA)    /AM, BG, GA, SN, OS, MA, MB, ME, PV, TG, ZM, ZC, LWCY,
             LWCO, LWEY, LWDY, MLK/
   PD1(PA)   /GA, SN, OS, TG, LWCY, LWCO, LWDY/
   PD2(PA)   /AM, BG, MA, MB, ME, PV, ZM, ZC, LWEY, MLK/
   PX(PA)    /AC, BG, GA, SN, OS, MA, MB, ME, PV, TG, ZM, ZC, LWCY,
             LWCO, LWEY, LWDY, MLK/
   PX1(PA)   /GA, SN, OS, PV, TG, ZM, ZC, LWCY, LWCO, LWEY, LWDY, MLK/
   PX2(PA)   /AC, BG, MA, MB, ME/
   QD(Q)     /DOM, REF/
   QD1(Q)    /DOM, REF/
   QD2(Q)    /DOM/
   QX(Q)     /EXP/
   PDQD(PA,Q)   /AC.REF,
                AM.DOM, AM.REF,
                GA.DOM,
                SN.DOM,
                OS.DOM,
                BG.DOM,
                MA.REF,
                MB.DOM,
                ME.DOM, ME.REF,
                PV.DOM,
                TG.DOM, TG.REF,
                ZM.DOM,
                ZC.DOM,
                LWCY.DOM,
                LWCO.DOM,
                LWEY.DOM,
                LWDY.DOM,
                MLK.DOM/
   PD2QD2(PA,Q) /AM.DOM,
                BG.DOM,
                MA.DOM,
                MB.DOM,
                ME.DOM,
                PV.DOM,
                ZM.DOM,
                ZC.DOM,
                LWEY.DOM,
```

```
             MLK.DOM/
*  JI(PA,Q)  //
  M          /JAN, FEB, MAR, APR, MAY, JUN, JUL, AUG, SEP, OCT, NOV, DEC/
  SE         /DRY, WET/
  SU         /NBAL soil nitrogen (N) balance
              PBAL soil phosphorus (P) balance
              KBAL soil potassium (K) balance
              NDEN denitrification
              NLEA N leaching
              NVOL N volatisation
              BIOA biocide active ingredient
              BIOI biocide index/
  D          /D0 * D100/
  LS         /L0 * L100/
  LS1(LS)    /L1 * L100/
  Y          /1997 * 2016/
;


* ----------------------------------------------------------------------
* 1.3 PARAMETER DECLARATIONS
* ----------------------------------------------------------------------

PARAMETERS

* Scaling factor
  SCALEFACT           factor to scale data up or down

* Coefficients of REALM model

* Objective function (OBJ) coefficients of optimisation part of REALM model
PRICEX(PX1,QX)       fixed export price in C. per ton
PRICED(PD,QD1)       fixed domestic price in C. per ton
PRICEI(PD,QD)        fixed import price in C. per ton
DOMEGAR(PD,QD2,D)    "area `below' regional domestic demand function at function limit D in C."
XRHOR(PX2,QX,D)      producer revenue at export demand function limit D in C.
OBJCOST              "`price' of input costs in C per 1000 C."
PRLTRAN(R,C,Q)       transportation costs of LUST products in C. per ton
PRHTRAN(R,HP,Q)      transportation costs of APST products in C. per ton
LABTRAN(RR,R)        labour transaction costs incurred by working
*                     in sub-region R coming from sub-region RR in C. per day
WAGERES(M)           reservation wage in each period in C. per day
WAGERESYR            reservation wage in whole year in C, per day
OUTTRAN(R)           labour transaction costs for outside NAZ labour per sub-region in C. per day
LABOMEGAYR(LS)       objective function coefficient associated with each segment
*                     limit LS of outside NAZ labour supply function in C.
PREMLUST(R,S,C,TL,TY) premium or tax on LUSTs in C. per ha
PREMPAST(R,S,P,SR)     premium or tax on PASTs in C. per ha

* Right-Hand-Side (RHS) coefficients of optimisation part of REALM model
SOIL_RSMX(R,S)       land availability per sub-region per soil type in ha
SOILM_RSMX(R,S)      land available for mechanisation per sub-region per soil type in ha
*                     (slope <= 25% and stoniness <= 1.5%)
LAB_RRMX(RR,M)       "labour availability per `from' sub-region per period in days"
SUST_RSMX(R,S,SU)    sustainability parameter SU limitation per sub-region per soil type
*                     in kg or index
SUST_RMX(R,SU)       sustainability parameter SU limitation per sub-region in kg or index
SUST_SMX(S,SU)       sustainability parameter SU limitation per soil type in kg or index
SUST_MX(SU)          sustainability parameter SU limitation in kg or index

* Input and output coefficients of optimisation part of REALM model
YIELDAL(S,C,TL,TY,Q) annuity yield of LUSTs in ton (1000 kg) per ha
YIELDAH(H,HP,Q)       annuity yield of HERDs in ton (1000 kg) per herd
SUSTL(S,C,TL,TY,SU)   value of sustainability indicator SU of LUSTs in kg or index per ha
SUSTP(S,P,SR,SU)      value of sustainability indicator SU of PASTs in kg or index per ha
COSTAL(S,C,TL,TY)     annuity of current input costs of LUSTs in 1000 C. per ha
COSTAH(H)             annuity of current input costs of APSTs in 1000 C. per herd
COSTAP(S,P,SR)        annuity of current input costs of PASTs in 1000 C. per ha
COSTAF(F)             annuity of current input costs of feed supplements in 1000 C. per kg
LWCINP(H)             calves as inputs for fattening systems in ton per herd
LABAL(S,C,TL,TY,M)    annuity of labour requirements of LUSTs in days per ha per period
LABAH(H,M)            annuity of labour requirements of APSTs in days per herd per period
LABAP(S,P,SR,M)       annuity of labour requirements of PASTs in days per ha per period
LABAF(F)              annuity of labour requirements of feed supplements in days per kg
TRANLUST(PA,C)        auxiliary coefficient to transfer LUST products into general products
TRANAPST(PA,HP)       auxiliary coefficient to transfer APST products into general products
TRANSFEXDO(PX,QX,PD,QD) transfer of export products not exported to domestic markets
DQUANTR(PD,QD2,D)     annuity of regional quantity at segment limit D of domestic
*                      demand function in tons
XQUANTR(PX2,QX,D)     annuity of regional quantity at segment limit D of export
*                      demand function in tons
```

```
LABNOF(M,LS)         annuity of outside NAZ labour at segment limit LS of labour
*                     supply function per period in days
LABNOFYR(LS)         annuity of outside NAZ labour at segment limit LS of labour
*                     supply function in days
SRATE(S,P,SR)        stocking rate of PAST in animal units per ha
HSIZE(H)             herd size of APST in animal units
HNUTPSE(S,P,SR,SE,HN) herd nutrition items supplied by PAST in kg or Mcal per ha per season
*                      or Mcal per kg
HNUTHSE(H,HN,SE)     herd nutrition items required by APST in kg or Mcal per herd per season
HNUTF(F,HN)          herd nutrition items supplied by feed supplements in kg or Mcal per kg
;


* -------------------------------------------------------------------------
* 1.4 VARIABLE DECLARATIONS
* -------------------------------------------------------------------------

VARIABLES

* Variables of optimization part of REALM model

vZ                  objective function value in C.

vLUST(R,S,C,TL,TY)  land use system & technology (LUST) per sub-region in ha
vPAST(R,S,P,SR)     "pasture, technology & stocking rate (PAST) per sub-region in ha"
vSFEDSE(R,F,SE)     use of supplementary feed per sub-region per season in kg of Mcal
vAPST(R,H)          animal production system & technology (APST) or herd type
*                    per sub-region in number of herds

vPROD(PA,Q)         "annuity of total production of product PA,Q in tons"
vPRODL(C,Q)         "annuity of total production of product C,Q of LUSTs in tons"
vPRODH(HP,Q)        "annuity of total production of product HP,Q of APSTs in tons"
vLUSTPROD(PA,C,Q)   auxiliary LUST product variable in tons
vAPSTPROD(PA,HP,Q)  auxiliary APST product variable in tons
vPRODLR(C,Q,R)      "annuity of production of product C,Q of LUSTs in tons per sub-region"
vPRODHR(HP,Q,R)     "annuity of production of product HP,Q of APSTs in tons per sub-region"

vDOMDEM(PA,Q)       domestic demand for product in tons
vIMPORT(PA,Q)       imported product for domestic demand in tons
vEXPDEM(PA,Q)       export demand for product in tons
vTRAEXPDOM(PX,QX,PD,QD) transfer of products not exported to domestic market in tons
vD(PD,QD2,D)        domestic demand function segment limit D
vX(PX2,QX,D)        export demand segment limit D

vINPUTS             annuity of total input costs in 1000 C.
vINPUTSR(R)         annuity of input costs per sub-region in 1000 C.

vLABTRANYR(R,RR)    labour transfer from sub-region RR to sub-region R in days
vLABFARMYR          total NAZ labour in days
vLABFARMRY(R)       labour per sub-region in days
vLABOUTYR           total outside NAZ labour in days
vLABOUTRYR(R)       outside NAZ labour per sub-region in days
vLYR(LS)            labour supply function segment limit LS

vSUSTSR(S,R,SU)     sustainability parameters per soil type per sub-region in kg or index
vSUSTR(R,SU)        sustainability parameters per sub-region in kg or index
vSUSTS(S,SU)        sustainability parameters per soil type in kg or index
vSUST(SU)           sustainability parameters for whole NAZ in kg or index

* variables for after optimisation calculations
vCROPT_NAZ(C,TL,TY) land use per crop & technology for whole NAZ in ha
vLUSTS(S,C,TL,TY)   land use systems & technology (LUSTs) for whole NAZ in ha
vGRASS_NAZ(P,SR)    "pastures, technology and stocking rates for whole NAZ in ha"
vPASTS(S,P,SR)      "pastures, technology and stocking rates (PASTs) for whole NAZ in ha"
vAPST_NAZ(H)        animal production systems & technology (APSTs) for whole NAZ
*                    in number of animals
vSFED_NAZ(F)        use of supplementary feed in kg of Mcal
vSFEDSE_NZ(F,SE)    use of supplementary feed per season in kg of Mcal
;


* -------------------------------------------------------------------------
* 1.5 VARIABLE DEFINITIONS
* -------------------------------------------------------------------------

POSITIVE VARIABLES
vLUST, vPAST, vSFEDSE, vAPST, vPROD, vPRODL, vPRODH, vLUSTPROD, vAPSTPROD,
vPRODLR, vPRODHR, vDOMDEM, vIMPORT, vEXPDEM, vTRAEXPDOM, vD, vX,
vINPUTS, vINPUTSR, vLABTRAN, vLABFARM, vLABFARMR, vLABOUT, vLABOUTR, vL
vLABTRANYR, vLABFARMYR, vLABFARMRY, vLABOUTYR, vLABOUTRYR, vLYR
;
```

```
FREE VARIABLES
vZ, vSUSTSR, vSUSTR, vSUSTS, vSUST
;


* ----------------------------------------------------------------------
* 1.6 EQUATION DECLARATIONS
* ----------------------------------------------------------------------

EQUATIONS

oECONSURP            objective function: consumer & producer surplus in C.

bPRODUCTLR(C,Q,R)    annuity of product balances of LUSTs per sub-region in tons
bPRODUCTL(C,Q)       annuity of product balances of LUSTs in tons
bPRODUCTHR(HP,Q,R)   annuity of product balances of APSTS per sub-region in tons
bPRODUCTH(HP,Q)      annuity of product balances of APSTs in tons

bLUSTPROD(C,Q)       balance to convert LUST products into general products in tons
bAPSTPROD(HP,Q)      balance to convert APST porducts into general products in tons
bLUAPPROD(PA,Q)      balance collect general LUST & APST products in tons

bDOMCOMMOD(PD,QD)    domestic commodity balances in tons
bDOMDEMSEG(PD,QD2)   segmentation of domestic demand in tons
cDOMDEMCVX(PD,QD2)   domestic demand convex combination constraint

bEXPCOMMOD(PX,QX)    export commodity balances in tons
bEXPDEMSEG(PX2,QX)   segmentation of export demand in tons
cEXPDEMCVX(PX2,QX)   export demand convex combination constaint

bFEEDSE(R,HN,SE)     herd nutrition balance per sub-region per season in kg or Mcal
bSTOCK(R)            animal number balance per sub-region in animal units
bCALVES              balance of calves in ton

bCOSTR(R)            annuity of input cost balance per sub-region in 1000 C.
bCOST                annuity of input cost balance in 1000 C.

cLAND(R,S)           constraint on land per sub-region per soil type in ha
cLANDMECH(R,S)       constraint on mechanisible land per sub-region per soil type in ha
*                     (slope <= 25% and stoniness <= 1.5%)

bLABOURR(R)          annuity of labour use balanced by labour supply in days
cLABONFRR(RR)        "NAZ labour availability per `from' sub-region in days"
bLABONFR(R)          calculation of NAZ labour use per sub-region in days
bLABONF              calculation of NAZ labour use in days
bLABNOF              calculation of outside NAZ labour supply in days
bLABNOFSEG           segmentation of outside NAZ labour supply function in days
cLABNOFCVX           convex combination constraint for outside NAZ labour supply

bSUSTSR(S,R,SU)      calculation of sustainability parameters per soil type per sub-region
*                     in kg or index
*cSUSTSR(S,R,SU)      constraint to sustainability parameters per soil type per sub-region
*                     in kg or index
bSUSTR(R,SU)         calculation of sustainability parameters per sub-region in kg or index
*cSUSTR(R,SU)         constraint to sustainability parameters per sub-region in kg or index
bSUSTS(S,SU)         calculation of sustainability parameters per soil type in kg or index
*cSUSTS(S,SU)         constraint to sustainability parameters per soil type in kg or index
bSUST(SU)            calculation of sustainability parameters in kg or index
cSUST(SU)            constraint to sustainability parameters in kg or index
;
```

```
* ----------------------------------------------------------------------
* 1.7 EQUATION DEFINITIONS
* ----------------------------------------------------------------------

* objective function
oECONSURP ..  vZ =E=
     SUM((PD,QD1), PRICED(PD,QD1) * vDOMDEM(PD,QD1))
   + SUM((PD,QD2,D), DOMEGAR(PD,QD2,D) * vD(PD,QD2,D))
   + SUM((PX1,QX), PRICEX(PX1,QX) * vEXPDEM(PX1,QX))
   + SUM((PX2,QX,D), XRHOR(PX2,QX,D) * vX(PX2,QX,D))
*   - SUM((PD,QD), PRICEI(PD,QD) * vIMPORT(PD,QD))
   - SUM((R,C,Q), PRLTRAN(R,C,Q) * vPRODLR(C,Q,R))
   - SUM((R,HP,Q), PRHTRAN(R,HP,Q) * vPRODHR(HP,Q,R))
   - OBJCOST * vINPUTS
   - SUM((R,RR), LABTRAN(RR,R) * vLABTRANYR(R,RR))
*   - WAGERESYR * vLABFARMYR
   - SUM((R), OUTTRAN(R) * vLABOUTRYR(R))
   - SUM((LS), LABOMEGAYR(LS) * vLYR(LS))
   + SUM((R,S,C,TL,TY), PREMLUST(R,S,C,TL,TY) * vLUST(R,S,C,TL,TY))
*   + SUM((R,S,P,SR), PREMPAST(R,S,P,SR) * vPAST(R,S,P,SR))
;

* crop production calculations
bPRODUCTLR(C,Q,R)$CQ(C,Q) ..
     SUM((S,TL,TY)$LP(S,C,TL,TY), - YIELDAL(S,C,TL,TY,Q) * vLUST(R,S,C,TL,TY))
   + vPRODLR(C,Q,R) =L= 0 ;
bPRODUCTL(C,Q)$CQ(C,Q) ..
   - SUM((R)$CQ(C,Q), vPRODLR(C,Q,R)) + vPRODL(C,Q) =L= 0 ;
* animal production calculations
bPRODUCTHR(HP,Q,R)$HPQ(HP,Q) ..
     SUM((H)$HPQ(HP,Q), - YIELDAH(H,HP,Q) * vAPST(R,H))
   + vPRODHR(HP,Q,R) =L= 0 ;
bPRODUCTH(HP,Q)$HPQ(HP,Q) ..
   - SUM((R)$HPQ(HP,Q), vPRODHR(HP,Q,R)) + vPRODH(HP,Q) =L= 0 ;

* conversion of crop & animal products to 'general' products
bLUSTPROD(C,Q)$CQ(C,Q) ..
     SUM((PA)$CQ(C,Q), TRANLUST(PA,C) * vLUSTPROD(PA,C,Q)) =E= vPRODL(C,Q) ;
bAPSTPROD(HP,Q)$HPQ(HP,Q) ..
     SUM((PA)$HPQ(HP,Q), TRANAPST(PA,HP) * vAPSTPROD(PA,HP,Q)) =E=
   + vPRODH(HP,Q) ;
bLUAPPROD(PA,Q) ..
   + vPROD(PA,Q) =E=
     SUM((C)$CQ(C,Q), TRANLUST(PA,C) * vLUSTPROD(PA,C,Q))
   + SUM((HP)$HPQ(HP,Q), TRANAPST(PA,HP) * vAPSTPROD(PA,HP,Q)) ;

* domestic demand equations
bDOMCOMMOD(PD,QD)$PDQD(PD,QD) ..
   - vPROD(PD,QD) + vDOMDEM(PD,QD)
   - SUM((PX,QX), TRANSFEXDO(PX,QX,PD,QD) * vTRAEXPDOM(PX,QX,PD,QD)) =L= 0 ;
bDOMDEMSEG(PD,QD2)$PD2QD2(PD,QD2) ..
   - vDOMDEM(PD,QD2)
   + SUM((D)$PD2QD2(PD,QD2), DQUANTR(PD,QD2,D) * vD(PD,QD2,D)) =L= 0 ;
cDOMDEMCVX(PD,QD2)$PD2QD2(PD,QD2) ..
     SUM((D)$PD2QD2(PD,QD2), vD(PD,QD2,D)) =L= 1 ;

* export demand equations
bEXPCOMMOD(PX,QX) ..
   - vPROD(PX,QX) + vEXPDEM(PX,QX)
   + SUM((PD,QD), TRANSFEXDO(PX,QX,PD,QD) * vTRAEXPDOM(PX,QX,PD,QD)) =L= 0 ;
bEXPDEMSEG(PX2,QX) ..
   - vEXPDEM(PX2,QX) + SUM(D, XQUANTR(PX2,QX,D) * vX(PX2,QX,D)) =L= 0 ;
cEXPDEMCVX(PX2,QX) ..
     SUM(D, vX(PX2,QX,D)) =L= 1 ;

* feed, animal and calves balances
bFEEDSE(R,HN,SE) ..
     SUM((P,S,SR)$PP(S,P,SR), HNUTPSE(S,P,SR,SE,HN) * vPAST(R,S,P,SR))
   + SUM((F), HNUTF(F,HN) * vSFEDSE(R,F,SE)) =G=
   + SUM((H), HNUTHSE(H,HN,SE) * vAPST(R,H)) ;
bSTOCK(R) ..
     SUM((P,S,SR)$PP(S,P,SR), SRATE(S,P,SR) * vPAST(R,S,P,SR))
     =E= SUM((H), HSIZE(H) * vAPST(R,H)) ;
bCALVES ..
     SUM((R,H), YIELDAH(H,"LWCY","EXP") * vAPST(R,H)) =G=
   + SUM((R,H), LWCINP(H) * vAPST(R,H)) ;
```

```
 * cost of inputs calculations
 bCOSTR(R) ..
      SUM((S,C,TL,TY)$LP(S,C,TL,TY), COSTAL(S,C,TL,TY) * vLUST(R,S,C,TL,TY))
    + SUM((H), COSTAH(H) * vAPST(R,H))
    + SUM((H), (LWCINP(H) * PRICEX("LWCY","EXP") / SCALEFACT)  * vAPST(R,H))
    + SUM((S,P,SR)$PP(S,P,SR), COSTAP(S,P,SR) * vPAST(R,S,P,SR))
    + SUM((F,SE), COSTAF(F) * vSFEDSE(R,F,SE))
    - vINPUTSR(R) =L= 0 ;
bCOST ..
      SUM(R, vINPUTSR(R)) - vINPUTS =L= 0 ;

* land restrictions
cLAND(R,S) ..
      SUM((C,TL,TY)$LP(S,C,TL,TY), vLUST(R,S,C,TL,TY))
   + SUM((P,SR)$PP(S,P,SR), vPAST(R,S,P,SR))  =L= SOIL_RSMX(R,S) ;
cLANDMECH(R,S) ..
      SUM((C,TL,TY)$LM(S,C,TL,TY), vLUST(R,S,C,TL,TY))
      =L= SOILM_RSMX(R,S) ;

* labour balances & restrictions
bLABOURR(R) ..
      SUM((S,C,TL,TY,M)$LP(S,C,TL,TY), LABAL(S,C,TL,TY,M) * vLUST(R,S,C,TL,TY))
    + SUM((H,M), LABAH(H,M) * vAPST(R,H))
    + SUM((S,P,SR,M), LABAP(S,P,SR,M) * vPAST(R,S,P,SR))
    + SUM((F,SE), LABAF(F) * vSFEDSE(R,F,SE))
    - SUM((RR), vLABTRANYR(R,RR))
    - vLABOUTRYR(R) =L= 0 ;
 cLABONFRR(RR) ..
      SUM((R), vLABTRANYR(R,RR)) =L= SUM(M, LAB_RRMX(RR,M)) ;
 bLABONFR(R) ..
      SUM((RR), vLABTRANYR(R,RR)) =E=  vLABFARMRY(R) ;
 bLABONF ..
      SUM((R), vLABFARMRY(R)) =E= vLABFARMYR ;
 bLABNOF ..
      SUM((R), vLABOUTRYR(R)) =E= vLABOUTYR ;
 bLABNOFSEG ..
    + vLABFARMYR + vLABOUTYR - SUM((LS), LABNOFYR(LS) * vLYR(LS)) =L= 0 ;
 cLABNOFCVX ..
      SUM((LS), vLYR(LS)) =L= 1 ;

 * sustainability and environmental balances & restrictions
 bSUSTSR(S,R,SU) ..
      SUM((C,TL,TY)$LP(S,C,TL,TY), SUSTL(S,C,TL,TY,SU) * vLUST(R,S,C,TL,TY))
    + SUM((P,SR)$PP(S,P,SR), SUSTP(S,P,SR,SU) * vPAST(R,S,P,SR))
    - vSUSTSR(S,R,SU) =E= 0 ;
 *cSUSTSR(S,R,SU) ..
 *   + vSUSTSR(S,R,SU) =L= SUST_RSMX(R,S,SU) ;
 bSUSTR(R,SU) ..
      SUM(S, vSUSTSR(S,R,SU)) - vSUSTR(R,SU) =E= 0 ;
 *cSUSTR(R,SU) ..
 *   + vSUSTR(R,SU) =L= SUST_RMX(R,SU) ;
 bSUSTS(S,SU) ..
      SUM(R, vSUSTSR(S,R,SU)) - vSUSTS(S,SU) =E= 0 ;
 *cSUSTS(S,SU) ..
 *   + vSUSTS(S,SU) =L= SUST_SMX(S,SU) ;
 bSUST(SU) ..
      SUM(S, vSUSTS(S,SU)) - vSUST(SU) =E= 0 ;
 cSUST(SU) ..
    + vSUST(SU) =L= SUST_MX(SU) ;


 * ---------------------------------------------------------------------
 * 1.8 MODEL DEFINITION
 * ---------------------------------------------------------------------

 MODEL REALM /ALL/
 ;


 * ---------------------------------------------------------------------
 * 1.9 PARAMETER DEFINITIONS
 *     DATA ARE READ FROM A NUMBER OF EXTERNAL FILES
 * ---------------------------------------------------------------------

 * Read Tables concerning soil/land availability
 * TABLE SOIL_RSMX(R,S), TABLE SOILM_RSMX(R,S)
 $INCLUDE C:\USR\REALM\ECONOM\INPDATA\LAND.PRN

 * Read Tables concerning labour availability
 * Paramater HLAB_RRMX(RR)
 $INCLUDE C:\USR\REALM\ECONOM\INPDATA\LABOUR.PRN
```

```
* Read Tables concerning permissible sustainability effects
* TABLE HSUST_RSMX(S,SU), PARAMETER CON_NPKBAL
$INCLUDE C:\USR\REALM\ECONOM\INPDATA\SUSTAIN.PRN

* Read Tables concerning scaling factors and other scalars
* SCALEFACT, DISCRATE, OBJCOST_E3, DPOPULATP, DINCOMEP, WAGE_P, DOLAR
* LAB_RRP, LABOUTP, LABNATP, LABNAZFACT, EMPLOYFRAC, LABNATPERS, LABSUPE, LABDEME
* TRIPDAY, SOILREDUC, DLRCHAN, TRSINFL
$INCLUDE C:\USR\REALM\ECONOM\INPDATA\SCALAR.PRN

* Read Tables concerning product prices, markets and elasticities
* Tables PRICEX_E3(PX1,QX), PRICED_E3(PD,QD1)
* DINCELAS(PD,QD2), DOMELAS(PD,QD2), DQUANTI_E3(PD,QD2), DPRICE0_E3(PD,QD2)
* DREGSHARE(PD,QD2), DFACTMIN(PD,QD2), DFACTMAX(PD,QD2), DSUPELAS(PD,QD2)
* XPOPULATP(PX2,QX), XINCOMEP(PX2,QX), XINCELAS(PX2,QX), XFACTMIN(PX2,QX)
* XFACTMAX(PX2,QX), EXPELAS(PX2,QX), XQUANTI_E3(PX2,QX), XPRICE0_E3(PX2,QX)
* XNATSHARE(PX2,QX), XREGSHARE(PX2,QX), XSUPELAS(PX2,QX)
$INCLUDE C:\USR\REALM\ECONOM\INPDATA\PRICE.PRN

* Read Tables concerning transport prices
* Tables PRLTRAN_E3(R,C,Q),PRHTRAN_E3(R,HP,Q)
$INCLUDE C:\USR\REALM\ECONOM\INPDATA\TRANSP.PRN

* Read Tables concerning wages
* Parameters WAGERES(M), WAGEMIN(M), WAGE0(M), PERIODDAY(M), OUTTRAN_A(R)
* TABLE LABTRAN_A(RR,R)
$INCLUDE C:\USR\REALM\ECONOM\INPDATA\WAGES.PRN

* Read Tables concerning premiums or taxes on LUSTs and PASTs
* Parameters PRETAXLUST(), PRETAXPAST()
* TABLE PRETAXLUST(C)
$INCLUDE C:\USR\REALM\ECONOM\INPDATA\PRETAX.PRN

* Tables with generated Technical Coefficients
* Yields
TABLE
YIELDAL_E3(S,C,TL,TY,Q)
$INCLUDE C:\USR\REALM\ECONOM\TCCROP\LUST_YLD.PRN

TABLE
YIELDAH_E3(H,HP)  annuity yield of HERDs in kg per herd
$INCLUDE C:\USR\REALM\ECONOM\TCPASTO\HERDP.PRN

PARAMETER
COSTAL_E3(S,C,TL,TY)
$INCLUDE C:\USR\REALM\ECONOM\TCCROP\LUST_CST.PRN

TABLE
COSTAP_E3(S,P,SR,*)  annuity of current input costs of PASTs in C. per ha
$INCLUDE C:\USR\REALM\ECONOM\TCPASTO\GRASC.PRN

PARAMETER
COSTAH_E3(H)  annuity of current input costs of APSTs in C. per herd
$INCLUDE C:\USR\REALM\ECONOM\TCPASTO\HERDC.PRN

PARAMETER
COSTAF_E3(F)  annuity of costs of feed supplements
$INCLUDE C:\USR\REALM\ECONOM\TCPASTO\FEEDC.PRN

* live calves as input for fattening
PARAMETER
LWCINP_E3(H)
$INCLUDE C:\USR\REALM\ECONOM\TCPASTO\HERDINP.PRN

* Labour
TABLE
LABAL_A(S,C,TL,TY,*)
$INCLUDE C:\USR\REALM\ECONOM\TCCROP\LUST_LAB.PRN

TABLE
LABAH_A(H,*)  annuity of labour requirements of APSTs in days per herd per period
$INCLUDE C:\USR\REALM\ECONOM\TCPASTO\HERDLM.PRN

TABLE
LABAP_A(S,P,SR,M,*)  annuity of labour requirements of PASTs in days per ha per period
$INCLUDE C:\USR\REALM\ECONOM\TCPASTO\GRASLM.PRN

TABLE
LABAF_A(F,*)  annuity of labour requirements of feed supplements in days per kg
$INCLUDE C:\USR\REALM\ECONOM\TCPASTO\FEEDL.PRN
```

```
 * Sustainability
 TABLE
 SUSTL_A(S,C,TL,TY,SU)
 $INCLUDE C:\USR\REALM\ECONOM\TCCROP\LUST_SUS.PRN

TABLE
SUSTP_A(S,P,SR,SU)  value of sustainability indicator SU of PASTs in kg or index per ha
$INCLUDE C:\USR\REALM\ECONOM\TCPASTO\GRASS.PRN

* Technical coefficients pasture
TABLE
PASTURE(S,P,SR,M,*)     herd nutritions & stocking rate & energy surplus & supplied dry matter
$INCLUDE C:\USR\REALM\ECONOM\TCPASTO\GRASPM.PRN

* Technical coefficients herds
TABLE
HERD(H,*)               herd size & nutrition requirements of APST
$INCLUDE C:\USR\REALM\ECONOM\TCPASTO\HERDR.PRN

* Technical coefficients feed supplements
TABLE
HNUTF(F,HN)         herd nutrition items supplied by feed supplements in kg
*                    or Mcal per kg
$INCLUDE C:\USR\REALM\ECONOM\TCPASTO\FEEDP.PRN

* Tables that are merely used as 'transfer' tables
TABLE TRANLUST(PA,C)
      AC AM  BG  GA  SN  OS  MA  MB  ME  PV  TG  ZM  ZC
AC     1
AM        1
BG            1
GA                1
SN                    1
OS                        1
MA                            1
MB                                1
ME                                    1
PV                                        1
TG                                            1
ZM                                                1
ZC                                                    1
LWCY
LWCO
LWEY
LWDY
MLK
;

 TABLE TRANAPST(PA,HP)
      LWCY LWCO LWEY LWDY  MLK
 AC
 AM
 BG
 GA
 SN
 OS
 MA
 MB
 ME
 PV
 TG
 ZM
 ZC
 LWCY    1
 LWCO         1
 LWEY              1
 LWDY                   1
 MLK                         1
 ;
```

```
* Not exported products for domestic market
TABLE TRANSFEXDO(PX,QX,PD,QD)
          AM.DOM BG.DOM GA.DOM SN.DOM OS.DOM MA.DOM MB.DOM ME.DOM PV.DOM TG.DOM ZM.DOM ZC.DOM LMCY.DOM LMCO.DOM LMEY.DOM LMDY.DOM MLK.DOM
AC.EXP       1
BG.EXP              1
GA.EXP                     1
SN.EXP                            1
CS.EXP                                   1
MA.EXP                                          1
MB.EXP                                                 1
ME.EXP                                                        1
PV.EXP                                                               1
TG.EXP                                                                      1
ZM.EXP                                                                             1
*ZC.EXP                                                                                   1
LMCY.EXP                                                                                         1
LMCO.EXP                                                                                                  1
LMEY.EXP                                                                                                           1
LMDY.EXP                                                                                                                    1
MLK.EXP                                                                                                                              1
;



*======================================================================*
*  2. ASSIGNMENTS AND PRE-CALCULATIONS ON DATA AND COEFFICIENTS        *
*======================================================================*


* ---------------------------------------------------------------------
* 2.1 PARAMETER DECLARATIONS
* ---------------------------------------------------------------------

PARAMETERS
* Coefficients used in assignments in order to establish the coefficients of
* the optimisation part of the REALM model

* Discount rate, discount factor and annuity factor
  DISCRATE              "discount rate (%/100)"
  DISCFACTY(Y)          discount factor in each year Y
  ANNUFACT              annuity factor

* Others
  SOILREDUC             reduction factor of available land due to roads, rivers and cities (-)
  DLRCHAN               revalue average 1994-1995-1996 dollar exchange rate to 1996 level
  TRSINFL               specific inflation rate transport costs 1995-1996
  PRETAXLUST(C)         premium or tax on LUSTs in C. per ha
*  PRETAXPAST(P)         premium or tax on PASTs in C. per ha

* Domestic population and income growth during planning period resulting in
  shifts of domestic demand functions
  DPOPULATP             "average domestic population growth fraction (%/100)"
  DINCOMEP              "average domestic income growth fraction (%/100)"
  DINCELAS(PD,QD2)      domestic demand income elasticity
  DQUANTP(PD,QD2)       "average shift of domestic demand function (%/100)"
  DQUANTI(PD,QD2)       initial domestic demand quantity in tons
  DQUANTEND(PD,QD2)     last year of planning horizon domestic demand quantity in tons
  DQUANTY(PD,QD2,Y)     domestic demand quantity in year Y in tons
  DPQUANTY(PD,QD2)      " `present domestic demand quantity' in initial year in tons"
  DAQUANTY(PD,QD2)      annuity of present present domestic demand quantity in tons

* Downward sloping domestic demand function coefficients
  DOMELAS(PD,QD2)       domestic demand price elasticity
  DPRICE0(PD,QD2)       initial domestic demand base price in C. per ton
  DQUANT0(PD,QD2)       domestic demand base quantity in tons
  DREGSHARE(PD,QD2)     regional fraction of domestic demand
  DQUANTR0(PD,QD2)      regional part of domestic demand base quantity in tons
  DQUANTRMIN(PD,QD2)    minimum regional production for domestic demand in tons
  DQUANTRMAX(PD,QD2)    maximum regional production for domestic demand in tons
  DINCRQUANT(PD,QD2)    incremental regional production for domestic demand in tons
*  DQUANTR(PD,QD2,D)     regional quantity at domestic demand segment limit D in tons; see also
*                        under 'input and output' coefficients
  DQUANT(PD,QD2,D)      national quantity at domestic demand segment limit D in tons
  DPRICE(PD,QD2,D)      prices at national domestic  demand function at limit D in C. per ton
  DQUANTREV(PD,QD2,D)   revised domestic quantity at limit D in tons
  DREGSHREV(PD,QD2,D)   revised regional fraction in domestic quantity at limit D
  DSUPELAS(PD,QD2)      "supply price elasticity of 'other' regions for domestic demand"
  DELASREV(PD,QD2,D)    revised regional domestic demand price elasticity at limit D
  DPRICEREV(PD,QD2,D)   revised domestic price at limit D in C. per ton
  DBETAR(PD,QD2,D)      regional domestic demand function BETA at limit D in C. per ton^2
  DALPHAR(PD,QD2,D)     regional domestic demand function ALPHA at limit D in C. per ton
*  DOMEGAR(PD,QD2,D)     " 'below' regional domestic demand function area at limit D in C. "
*                        see also unde objective function coefficients
  DRHOR(PD,QD2,D)       producer revenue at limit D associated with regional domestic demand function
*                        in C.
```

```
* Foreign population and income growth during planning period resulting in
  shifts of export demand functions
  XPOPULATP(PX2,QX)      "average foreign population growth fraction (%/100) per product"
  XINCOMEP(PX2,QX)       "average foreign income growth fraction (%/100) per product"
  XINCELAS(PX2,QX)       export demand income elasticity
  XQUANTP(PX2,QX)        "average shift of export demand function (%/100)"
  XQUANTI(PX2,QX)        initial export demand quantity in tons
  XQUANTEND(PX2,QX)      last year of planning horizon export demand quantity in tons
  XQUANTY(PX2,QX,Y)      export demand quantity in year Y in tons
  XPQUANTY(PX2,QX)       " `present export demand quantity' in initial year in tons"
  XAQUANTY(PX2,QX)       annuity of present present export demand quantity in tons

* Downward sloping domestic export function coefficients
  EXPELAS(PX2,QX)        export demand price elasticity
  XPRICE0(PX2,QX)        "initial export demand ('world' market) base price in C. per ton"
  XQUANT0(PX2,QX)        "export demand ('world' market) base quantity in tons "
  XREGSHARE(PX2,QX)      regional fraction in export demand
  XNATSHARE(PX2,QX)      national fraction in world market
  XQUANTR0(PX2,QX)       regional part of export demand base quantity in tons
  XQUANTRMIN(PX2,QX)     minimum regional production for export demand in tons
  XQUANTRMAX(PX2,QX)     maximum regional production for export demand in tons
  XINCRQUANT(PX2,QX)     incremental regional production for export demand in tons
*  XQUANTR(PX2,QX,D)      regional quantity at export demand segment limit D in tons; see also
*                         input and output coefficients
  XQUANT(PX2,QX,D)       national quantity at export demand segment limit D in tons
  XPRICE(PX2,QX,D)       prices at export demand function at limit D in C. per tons
  XQUANTREV(PX2,QX,D)    revised export quantity at limit D in tons
  XREGSHREV(PX2,QX,D)    revised regional fraction in export quantity at limit D
  XSUPELAS(PX2,QX)       "supply price elasticity of 'other' regions and countries for world market demand"
  XELASREV(PX2,QX,D)     revised regional export demand price elasticity at limit D
  XPRICEREV(PX2,QX,D)    revised export price at limit D in C. per tons
  XBETAR(PX2,QX,D)       regional export demand function BETA at limit D in C. per tons^2
  XALPHAR(PX2,QX,D)      regional export demand function ALPHA at limit D in C. per tons
  XOMEGAR(PX2,QX,D)      " 'below' regional export demand function area at limit D in C. "
*  XRHOR(PX2,QX,D)        producer revenue at limit D associated with regional export demand function
*                         in C.; see also under objective function coefficients

* Upward sloping national labour supply function coefficients
  LABSUPE                national labour supply elasticity
  LABSUPELAS(M)          national labour supply elasticity per period
  ALPHALAB(M)            constant ALPHA in upward sloping national labour supply function
  BETALAB(M)             coefficient BETA in upward sloping national labour linear supply function

* Labour availability coefficients
  HLAB_RRMX(RR)          agricultural labour force per sub-region in number of persons
*                         (older than 12 with work or unemployed or first time looking for work)
  LABNAZFACT             fraction of agricultural labour force available for work in agriculture
  LAB_RRP                "during planning period growth (%/100) of availability of labour"
*                         inside the sub-regions
  EMPLOYFRAC             fraction of NAZ labour without employment

  HLAB_RRMXE(RR)        last year of planning horizon availability of labour within sub-regions
*                        per sub-region per period in days
  HLAB_RRMXY(RR,Y)      availability of labour within sub-regions in year Y of planning horizon
*                        per sub-region per period in days

  PLAB_RRMXY(RR)         " 'present' availability of labour within each sub-region per period in days"
  ALAB_RRMXY(RR)         annuity of availability of labour within each sub-region per period in days
  SLAB_RRMX(M)           sum of labour availability for NAZ per period in days

  PERIODDAY(M)           number of days per period in days
  TRIPDAY                number of trips per day in case of labour from other sub-regions
*                         or from outside NAZ

  LABOUTI(M)             initial unemployed NAZ labour availability per period
  LABOUTP                during planning horizon growth (fraction) of availability of unemployed NAZ
*                         labour (unemployed) in days
  LABOUTY(M,Y)           availability of unemployed NAZ labour in year Y of planning horizon
*                         per period in days
  LABOUTEND(M)           last year of planning horizon availability of umemployed NAZ labour
*                         per period in days
  PLABOUTY(M)            " 'present' availability of unemployed NAZ labour per period in days"
  ALABOUTY(M)            annuity of availability of unemployed NAZ labour per period in days

  LABNATPERS             national labour availability in persons
*                        ("asalariados - profesion. y gerentes")
  LABNATI(M)             initial national labour availability in days per period
  LABNATP                "during planning horizon growth (%/100) of nation labour availability"
*                        in days
  LABNATEND(M)           last year of planning horizon national labour availability per period in days
  LABNATY(M,Y)           national labour availability in year Y of planning horizon per period in days
```

```
  PLABNATY(M)           " 'present' national labour availability per period in days"
  ALABNATY(M)           annuity of national labour availability per period in days
  LABNATO(M)            base year national labour availability per period in days

* Revised labour supply estimations
  LFACTLO               factor to obtain lower limit of NAZ labour supply function per period in days
  LFACTUP               factor to obtain upper limit of NAZ labour supply function per period in days
  LABNATLIM(M,LS)       national labour supply at segment limit LS per period in days
  LABDEME               national labour demand elasticity
  LABDEMELAS(M)         national labour demand elasticity per period
  LABNATREV(M,LS)       revised national labour supply per period in days
  LABSHARE(M,LS)        share of additional NAZ labour in national labour supply per period
  NAZLABELAS(M,LS)      NAZ labour supply elasticity at segment limit LS per period
  INTWAGEREV(M,LS)      (intermediate) revised wage at segment limt LS in Colones per day
  WAGEREV(M,LS)         revised wage at segment limit LS in Colones day
  SQUARE(M,LS)          SQUARE area below kinked NAZ labour supply function per period in Colones
  TRIANGLE(M,LS)        TRIANGLE area below kinked NAZ labour supply function per period in Colones

  WAGEMIN(M)            mimimum wage in Colones per day
  WAGEO(M)              base year wage in C. per day
  WAGE(M,LS)            wage at each segment limit of labour supply function

  WAGE_P                average growth of wages per year (fraction) during planning horizon
  ENDWAGFACT            factor for wage increase in end-of-planning period year
  A_WAGFACT(Y)          year Y factor for wage increase during planning period
  P_WAGFY               present value of annual wage increase factor
  A_WAGFY               annuity of annual wage increase factor

  BETALAB2(M)           coefficient BETA of upward sloping labour supply function
  ALPHALAB2(M)          coefficient ALPHA of upward sloping labour supply function
  LABOUTO(M)            base year labour supply in days
  LABOUTLO(M)           lower limit of labour supply function
  LABOUTUP(M)           upper limit of labour supply function
  LABOUTINCR(M)         incremental labour supply between lower and upper limit
  LABOUT(M,LS)          labour supply at each segment limit of labour supply function
  LABOMEGA(M,LS)        objective function coefficient associated at each segment limit
*                        of labour supply function (at present used in an assignment)
*  LABRHO(M,LS)         producer labour costs at each segment limit of labour supply fucntion

* Permissable sustainability effects
HSUST_RSMX(S,SU)        permissible sustainability effects per soil type per ha
CON_NPKBAL(SU)

* Rescaling
YIELDAL_E3(S,C,TL,TY,Q) annuity yield of LUSTs in kg per ha
YIELDAH_E3(H,HP)        annuity yield of HERDs in kg per herd
PRICEX_E3(PX1,QX)       fixed export price in C. per kg
PRICED_E3(PD,QD1)     . fixed domestic price in C. per kg
XPRICE0_E3(PX2,QX)      "initial export demand ('world' market) base price in C. per kg"
DPRICE0_E3(PD,QD2)      initial domestic demand base price in C. per kg
PRICEI_E3(PD,QD)        fixed import price in C. per kg   .
DQUANTI_E3(PD,QD2)      initial domestic demand quantity in kg
XQUANTI_E3(PX2,QX)      initial export demand quantity in kg
OBJCOST_E3              "`price' of input costs in C per C."
LWCINP_E3(H)            live calves as inputs for fattening systems in kg per herd
PRLTRAN_E3(R,C,Q)       transportation costs of LUST products in C. per kg
PRHTRAN_E3(R,HP,Q)      transportation costs of APST products in C. per kg
COSTAL_E3(S,C,TL,TY)    annuity of current input costs of LUSTs in C. per ha
COSTAH_E3(H)            annuity of current input costs of APSTs in C. per herd
COSTAP_E3(S,P,SR,*)     annuity of current input costs of PASTs in C. per ha
COSTAF_E3(F)            annuity of current input costs of feed supplements in C. per kg
LABAL_A(S,C,TL,TY,*)    annuity of labour requirements of LUSTs in days per ha per period
LABAH_A(H,*)            annuity of labour requirements of APSTs in days per herd per period
LABAP_A(S,P,SR,M,*)     annuity of labour requirements of PASTs in days per ha per period
LABAF_A(F,*)            annuity of labour requirements of feed supplements in days per kg
LABTRAN_A(RR,R)         labour transaction costs incurred by working
*                        in sub-region R coming from sub-region RR in C. per day
OUTTRAN_A(R)            labour transaction costs for outside NAZ labour per sub-region in C. per day

* Pasture data
PASTURE(S,P,SR,M,*)     herd nutritions & stocking rate & energy surplus & supplied dry matter
*                       of PASTs in kg or Mcal per ha

* Herd data
HERD(H,*)               herd size & nutrition requirements of APST
;
```

```
* -------------------------------------------------------------------------
* 2.2 PARAMETER DEFINITIONS (ASSIGNMENTS AND CALCULATIONS
* -------------------------------------------------------------------------

* reading the appropriate data
LABAL(S,C,TL,TY,M)        = LABAL_A(S,C,TL,TY,"CLABA") ;
LABAH(H,M)                = LABAH_A(H,"HLABA") ;
LABAP(S,P,SR,M)           = LABAP_A(S,P,SR,M,"GLABA") ;
LABAF(F)                  = LABAP_A(F,"FLABA") ;
SRATE(S,P,SR)             = PASTURE(S,P,SR,"JAN","SR") ;
HNUTPSE(S,P,SR,"DRY",HN)  = PASTURE(S,P,SR,"JAN",HN) * 3 ;
HNUTPSE(S,P,SR,"WET",HN)  = PASTURE(S,P,SR,"APR",HN) * 9 ;
HNUTHSE(H,HN,"DRY")       = HERD(H,HN) * 3 ;
HNUTHSE(H,HN,"WET")       = HERD(H,HN) * 9 ;
HSIZE(H)                  = HERD(H,"HSAU") ;

* Rescaling
YIELDAL(S,C,TL,TY,Q)     = YIELDAL_E3(S,C,TL,TY,Q) / SCALEFACT ;
YIELDAH(H,HP,"EXP")      = YIELDAH_E3(H,HP)        / SCALEFACT ;
COSTAL(S,C,TL,TY)        = COSTAL_E3(S,C,TL,TY)    / SCALEFACT ;
COSTAH(H)                = COSTAH_E3(H)            / SCALEFACT ;
COSTAP(S,P,SR)           = COSTAP_E3(S,P,SR,"COST") / SCALEFACT ;
COSTAF(F)                = COSTAF_E3(F)            / SCALEFACT ;
LWCINP(H)                = LWCINP_E3(H)            / SCALEFACT ;
PRICEX(PX1,QX)           = DLRCHAN * PRICEX_E3(PX1,QX)       * SCALEFACT ;
PRICED(PD,QD1)           = DLRCHAN * PRICED_E3(PD,QD1)       * SCALEFACT ;
XPRICE0(PX2,QX)          = DLRCHAN * XPRICE0_E3(PX2,QX)      * SCALEFACT ;
DPRICE0(PD,QD2)          = DLRCHAN * DPRICE0_E3(PD,QD2)      * SCALEFACT ;
DQUANTI(PD,QD2)          = DQUANTI_E3(PD,QD2)      / SCALEFACT ;
XQUANTI(PX2,QX)          = XQUANTI_E3(PX2,QX)      / SCALEFACT ;
*PRICEI(PD,QD)             = PRICEI_E3(PD,QD)        * SCALEFACT ;
OBJCOST                  = OBJCOST_E3              * SCALEFACT ;
PRLTRAN(R,C,Q)           = TRSINFL * PRLTRAN_E3(R,C,Q)       * SCALEFACT ;
PRHTRAN(R,HP,Q)          = TRSINFL * PRHTRAN_E3(R,HP,Q)      * SCALEFACT ;

SOIL_RSMX(R,S)           = SOILREDUC * SOIL_RSMX(R,S) ;
SOILM_RSMX(R,S)          = SOILREDUC * SOILM_RSMX(R,S) ;

* premiums or taxes on LUSTs or PASTs
  PREMLUST(R,S,C,TL,TY)$(LP(S,C,TL,TY) AND PRETAXLUST(C) NE 0) = PRETAXLUST(C) ;
*  PREMPAST(R,S,P,SR)      = PRETAXPAST(P) ;

* Labour transaction costs based on 1996 busfares, assuming one trip per week
LABTRAN(RR,R) = LABTRAN_A(RR,R) * TRIPDAY ;
OUTTRAN(R)    = OUTTRAN_A(R) * TRIPDAY ;

* Discount factors in each year Y and annuity factor of planning horizon
DISCFACTY(Y)               = POWER (1/(1+DISCRATE), ORD(Y)) ;
ANNUFACT$(DISCRATE GT 0) = (DISCRATE * POWER ((1+DISCRATE), CARD(Y))) /
                           (POWER ((1+DISCRATE), CARD(Y))-1) ;
ANNUFACT$(DISCRATE EQ 0) = 1/CARD(Y) ;


* Within sub-regions labour availability
* Calculate future labour availability within sub-regions (employed)
HLAB_RRMXE(RR)   = LABNAZFACT * EMPLOYFRAC * HLAB_RRMX(RR) * POWER((1 + LAB_RRP), CARD(Y)) ;
HLAB_RRMXY(RR,Y) = LABNAZFACT * EMPLOYFRAC * HLAB_RRMX(RR) * POWER((1 + LAB_RRP), ORD(Y)) ;
PLAB_RRMXY(RR)   = SUM((Y), HLAB_RRMXY(RR,Y) * DISCFACTY(Y)) ;
ALAB_RRMXY(RR)   = PLAB_RRMXY(RR) * ANNUFACT ;

* Select between `annuity' within sub-region labour (ALAB_RRMXY) availability
* or `end-of-planning-horizon-year` availability (HLAB_RRMXE)
LAB_RRMX(RR,M)   = PERIODDAY(M) * ALAB_RRMXY(RR) ;
*LAB_RRMX(RR,M)    = PERIODDAY(M) * HLAB_RRMXE(RR) ;

* Calculation of total NAZ labour availability per period in days
SLAB_RRMX(M)     = SUM(RR, LAB_RRMX(RR,M)) ;

* Unemployed NAZ labour availability
LABOUTI(M)       = SUM(RR, HLAB_RRMX(RR)) * PERIODDAY(M) * LABNAZFACT * (1 - EMPLOYFRAC) ;
* Continuation of unemployed NAZ labour availability calculation
LABOUTEND(M)     = LABOUTI(M) * POWER ((1 + LABOUTP), CARD(Y)) ;
LABOUTY(M,Y)     = LABOUTI(M) * POWER ((1 + LABOUTP), ORD(Y)) ;
PLABOUTY(M)      = SUM (Y, LABOUTY(M,Y) * DISCFACTY(Y)) ;
ALABOUTY(M)      = PLABOUTY(M) * ANNUFACT ;

* Select between `annuity' outside NAZ labour (ALABOUTY) availability
* or `end-of-planning-horizon-year` availability (LABOUTEND)
LABOUT0(M)       = ALABOUTY(M) ;
*LABOUT0(M)        = LABOUTEND(M) ;
```

```
* National labour availability
LABNATI(M)        = LABNATPERS * PERIODDAY(M) ;
* Continuation of national labour availabilty calculation
LABNATEND(M)      = LABNATI(M) * POWER ((1 + LABNATP), CARD(Y)) ;
LABNATY(M,Y)      = LABNATI(M) * POWER ((1 + LABNATP), ORD(Y)) ;
PLABNATY(M)       = SUM (Y, LABNATY(M,Y) * DISCFACTY(Y)) ;
ALABNATY(M)       = PLABNATY(M) * ANNUFACT ;

* Select between `annuity' outside NAZ labour (ALABNATY) availability
* or `end-of-planning-horizon-year` availability (LABNATEND)
LABNAT0(M)        = ALABNATY(M) ;
*LABNAT0(M)        = LABNATEND(M) ;

* Annual wage increases during planning period
ENDWAGFACT       = POWER ((1+ WAGE_P), CARD(Y)) ;
A_WAGFACT(Y)     = POWER ((1+ WAGE_P), ORD(Y)) ;
P_WAGFY          = SUM(Y, A_WAGFACT(Y) * DISCFACTY(Y)) ;
A_WAGFY          = P_WAGFY * ANNUFACT ;

* Select between `annuity' wages
* or `end-of-planning-horizon-year` wages
WAGERES(M)        = WAGERES(M) * A_WAGFY ;
*WAGERES(M)        = WAGERES(M) * ENDWAGFACT ;
WAGEMIN(M)        = WAGEMIN(M) * A_WAGFY ;
*WAGEMIN(M)        = WAGEMIN(M) * ENDWAGFACT ;
WAGE0(M)        = WAGE0(M) * A_WAGFY ;
*WAGE0(M)         = WAGE0(M) * ENDWAGFACT ;

* Reservation wage per day for whole year
WAGERESYR = SUM(M, WAGERES(M)) / CARD(M) ;

* calculation of 'alpha' & 'beta' of national upward sloping labour supply function
ABORT $(LABSUPE EQ 0) "Labour supply elasticity equal to ZERO" ;
DISPLAY "Labour supply elasticity not equal to zero" ;
LABSUPELAS(M)     = LABSUPE ;
BETALAB2(M)       = WAGE0(M) / (LABNAT0(M) * LABSUPELAS(M)) ;
ALPHALAB2(M)      = WAGE0(M) - BETALAB2(M) * LABNAT0(M) ;

* lower & upper limit NAZ labour supply function
LABOUTLO(M)       = LFACTLO * (SUM(RR, LAB_RRMX(RR,M)) + LABOUT0(M)) ;
LABOUTUP(M)       = LFACTUP * (SUM(RR, LAB_RRMX(RR,M)) + LABOUT0(M)) ;

* NAZ labour supply function segment limits
LABOUTINCR(M)     = (LABOUTUP(M) - (SUM(RR, LAB_RRMX(RR,M)) + LABOUT0(M))) / (CARD(LS1)-1) ;
LABNOF(M,"L0")    = LABOUTLO(M) ;
LABNOF(M,LS1)     = (SUM(RR, LAB_RRMX(RR,M)) + LABOUT0(M)) + (ORD(LS1)-1) * LABOUTINCR(M) ;
LABNOFYR(LS)      = SUM(M, LABNOF(M,LS)) ;

* national labour supply segment limits
LABNATLIM(M,LS)   = LABNOF(M,LS) + LABNAT0(M) - (SUM(RR, LAB_RRMX(RR,M)) + LABOUT0(M)) ;

* wages along national upward sloping labour supply function (only the section that is
* relevant, as defined above; the supply function is kinked, horizontal till LABNAT0)
WAGE(M,LS) $ (LABNATLIM(M,LS) LE LABNAT0(M)) = WAGE0(M) ;
WAGE(M,LS) $ (LABNATLIM(M,LS) GT LABNAT0(M)) = ALPHALAB2(M) + BETALAB2(M) * LABNATLIM(M,LS) ;

* revised national labour supply
ABORT $(LABDEME GT 0) "National labour demand elasticity larger than zero"  ;
DISPLAY "National labour demand elasticity less than or equal to zero" ;
LABDEMELAS(M)     = LABDEME ;
LABNATREV(M,LS)   = LABNATLIM(M,LS) + LABDEMELAS(M) * (LABNAT0(M) - LABOUT0(M)) *
                                      (WAGE(M,LS) - WAGE0(M)) / WAGE0(M) ;

* share additional NAZ labour in national labour
LABSHARE(M,LS)    = LABNOF(M,LS) / LABNATREV(M,LS) ;

* regional labour supply elasticity
NAZLABELAS(M,LS) = LABSUPELAS(M) / LABSHARE(M,LS)
                 - LABDEMELAS(M) * (1 - LABSHARE(M,LS)) / LABSHARE(M,LS) ;
INTWAGEREV(M,LS) $ (LABNATLIM(M,LS) LE LABNAT0(M)) = WAGE(M,LS) ;
INTWAGEREV(M,LS) $ (LABNATLIM(M,LS) GT LABNAT0(M)) = WAGE(M,LS) ;
INTWAGEREV(M,LS) $ (LABNATLIM(M,LS) GT LABNAT0(M)) = WAGE(M,LS-1)
                 + ((LABNOF(M,LS) - LABNOF(M,LS-1)) * INTWAGEREV(M,LS-1)) /
                   (NAZLABELAS(M,LS) * LABNOF(M,LS-1)) ;

* revised wage
WAGEREV(M,LS) $ (INTWAGEREV(M,LS) GT INTWAGEREV(M,LS+1)) = WAGE(M,LS) ;
WAGEREV(M,LS) $ (INTWAGEREV(M,LS) LE INTWAGEREV(M,LS+1)) = INTWAGEREV(M,LS) ;
```

```
* 'SQUARE' area below kinked NAZ labour supply function (per month)
SQUARE(M,LS)      = WAGE0(M) * LABNOF(M,LS) ;

* 'TRIANGLE' area below kinked NAZ labour supply function (per month)
TRIANGLE(M,LS)    = 0.5 * (LABNOF(M,LS) - LABOUT0(M)) * (WAGEREV(M,LS) - WAGE0(M)) ;

* area *below upward sloping NAZ labour supply function (per month)
LABOMEGA(M,LS)    = SQUARE(M,LS) + TRIANGLE(M,LS) ;

* Summing 'monthly' area below labour supply function to yearly figure
LABOMEGAYR(LS) = SUM(M, LABOMEGA(M,LS)) ;


* Converting negative nbal, pbal & kbal losses into positive figures
SUSTL(S,C,TL,TY,SU) = SUSTL_A(S,C,TL,TY,SU) * CON_NPKBAL(SU) ;
SUSTP(S,P,SR,SU)    = SUSTP_A(S,P,SR,SU) * CON_NPKBAL(SU) ;

* Permissible sustainability effecten
SUST_RSMX(R,S,SU)    = HSUST_RSMX(S,SU) * SOIL_RSMX(R,S) ;
SUST_RMX(R,SU)       = SUM(S, SUST_RSMX(R,S,SU)) ;
SUST_SMX(S,SU)       = SUM(R, SUST_RSMX(R,S,SU)) ;
SUST_MX(SU)          = SUM((R,S), SUST_RSMX(R,S,SU)) ;


* Base quantity domestic demand
DQUANTP(PD,QD2)      = DPOPULATP + DINCELAS(PD,QD2) * DINCOMEP ;
DQUANTEND(PD,QD2)    = DQUANTI(PD,QD2) * POWER ((1 + DQUANTP(PD,QD2)), CARD(Y)) ;
DQUANTY(PD,QD2,Y)    = DQUANTI(PD,QD2) * POWER ((1 + DQUANTP(PD,QD2)), ORD(Y)) ;
DPQUANTY(PD,QD2)     = SUM (Y, DQUANTY(PD,QD2,Y) * DISCFACTY(Y)) ;
DAQUANTY(PD,QD2)     = DPQUANTY(PD,QD2) * ANNUFACT ;

* Select between `annuity' base quantity domestic demand (DAQUANTY) or
* `end-of-planning-horizon-year' qauntity (DQUANTEND)
DQUANT0(PD,QD2)      = DAQUANTY(PD,QD2) ;
*DQUANT0(PD,QD2)      = DQUANTEND(PD,QD2) ;

* Regionalised downward sloping domestic demand functions
DQUANTR0(PD,QD2)     = DQUANT0(PD,QD2) * DREGSHARE(PD,QD2) ;

DQUANTRMIN(PD,QD2)$(DFACTMIN(PD,QD2) GT 0)  =
                       DQUANTR0(PD,QD2) / DFACTMIN(PD,QD2) ;

DQUANTRMAX(PD,QD2)   = DQUANTR0(PD,QD2) * DFACTMAX(PD,QD2) ;
DINCRQUANT(PD,QD2)   = (DQUANTRMAX(PD,QD2) - DQUANTRMIN(PD,QD2))/(CARD(D)-1) ;
DQUANTR(PD,QD2,D)    = DQUANTRMIN(PD,QD2) + (ORD(D)-1) * DINCRQUANT(PD,QD2) ;
DQUANT(PD,QD2,D)     = DQUANT0(PD,QD2) + DQUANTR(PD,QD2,D) - DQUANTR0(PD,QD2) ;

DPRICE(PD,QD2,D)$PD2QD2(PD,QD2)
                     = DPRICE0(PD,QD2) +
                    ((DQUANT(PD,QD2,D) - DQUANT0(PD,QD2)) * DPRICE0(PD,QD2))
                    /(DOMELAS(PD,QD2) * DQUANT0(PD,QD2)) ;

DQUANTREV(PD,QD2,D)$(DPRICE0(PD,QD2) GT 0) = DQUANTR(PD,QD2,D) +
                    (DQUANT(PD,QD2,D) - DQUANTR(PD,QD2,D)) +
                    DSUPELAS(PD,QD2) *
                    (DQUANT0(PD,QD2) - DQUANTR0(PD,QD2)) *
                    (DPRICE(PD,QD2,D) - DPRICE0(PD,QD2))/DPRICE0(PD,QD2) ;

DREGSHREV(PD,QD2,D)$(DQUANTREV(PD,QD2,D) GT 0)
                     = DQUANTR(PD,QD2,D)/DQUANTREV(PD,QD2,D) ;

DELASREV(PD,QD2,D)$(1-DREGSHREV(PD,QD2,D) GT 0 AND DREGSHREV(PD,QD2,D) GT 0)
                     = DOMELAS(PD,QD2)/DREGSHREV(PD,QD2,D)
                - DSUPELAS(PD,QD2) * (1-DREGSHREV(PD,QD2,D))/DREGSHREV(PD,QD2,D) ;

DPRICEREV(PD,QD2,D)$PD2QD2(PD,QD2) = DPRICE0(PD,QD2) ;
DPRICEREV(PD,QD2,D)$(DQUANT(PD,QD2,D) LT DQUANT0(PD,QD2) AND DQUANTR(PD,QD2,D+1) GT 0
          AND DELASREV(PD,QD2,D) LT 0) =
          DPRICE(PD,QD2,D+1) +
          ((DQUANTR(PD,QD2,D) - DQUANTR(PD,QD2,D+1)) * DPRICEREV(PD,QD2,D+1)) /
          (DELASREV(PD,QD2,D) * DQUANTR(PD,QD2,D+1)) ;
DPRICEREV(PD,QD2,D)$(DQUANT(PD,QD2,D) GE DQUANT0(PD,QD2) AND DQUANTR(PD,QD2,D-1) GT 0
          AND DELASREV(PD,QD2,D) LT 0) =
          DPRICE(PD,QD2,D-1) +
          ((DQUANTR(PD,QD2,D) - DQUANTR(PD,QD2,D-1)) * DPRICEREV(PD,QD2,D-1)) /
          (DELASREV(PD,QD2,D) * DQUANTR(PD,QD2,D-1)) ;
DPRICEREV(PD,QD2,D)$(DELASREV(PD,QD2,D) EQ 0) = 0 ;
```

```
DBETAR(PD,QD2,D)$(DQUANTR(PD,QD2,D) GT 0 AND DPRICEREV(PD,QD2,D) GT 0
              AND DELASREV(PD,QD2,D) LT 0)  =
              - DPRICEREV(PD,QD2,D) / (DELASREV(PD,QD2,D) * DQUANTR(PD,QD2,D)) ;
DALPHAR(PD,QD2,D)$(DELASREV(PD,QD2,D) LT 0 AND DPRICEREV(PD,QD2,D) GT 0) =
                      DPRICEREV(PD,QD2,D)
                      + DBETAR(PD,QD2,D) * DQUANTR(PD,QD2,D) ;

DOMEGAR(PD,QD2,D)   = DALPHAR(PD,QD2,D) * DQUANTR(PD,QD2,D)
                      - 0.5 * DBETAR(PD,QD2,D) * SQR(DQUANTR(PD,QD2,D)) ;
DRHOR(PD,QD2,D)     = DALPHAR(PD,QD2,D) * DQUANTR(PD,QD2,D)
                      - DBETAR(PD,QD2,D) * SQR(DQUANTR(PD,QD2,D)) ;


* Base quantity export demand
XQUANTP(PX2,QX)     = XPOPULATP(PX2,QX) + XINCELAS(PX2,QX) * XINCOMEP(PX2,QX) ;
XQUANTEND(PX2,QX)   = XQUANTI(PX2,QX) * POWER ((1 + XQUANTP(PX2,QX)), CARD(Y)) ;
XQUANTY(PX2,QX,Y)   = XQUANTI(PX2,QX) * POWER ((1 + XQUANTP(PX2,QX)), ORD(Y)) ;
XPQUANTY(PX2,QX)    = SUM (Y, XQUANTY(PX2,QX,Y) * DISCFACTY(Y)) ;
XAQUANTY(PX2,QX)    = XPQUANTY(PX2,QX) * ANNUFACT ;

* Select between `annuity' base quantity domestic demand (DAQUANTY) or
* `end-of-planning-horizon-year' qauntity (DQUANTEND)
XQUANTO(PX2,QX)     = XAQUANTY(PX2,QX) ;
*XQUANTO(PX2,QX)     = XQUANTEND(PX2,QX) ;

* Regionalised downward sloping export demand functions
XQUANTRO(PX2,QX)    = XQUANTO(PX2,QX) * XREGSHARE(PX2,QX) * XNATSHARE(PX2,QX) ;
XQUANTRMIN(PX2,QX)  = XQUANTRO(PX2,QX) / XFACTMIN(PX2,QX) ;
XQUANTRMAX(PX2,QX)  = XQUANTRO(PX2,QX) * XFACTMAX(PX2,QX) ;
XINCRQUANT(PX2,QX)  = (XQUANTRMAX(PX2,QX) - XQUANTRMIN(PX2,QX))/(CARD(D)-1) ;
XQUANTR(PX2,QX,D)   = XQUANTRMIN(PX2,QX) + (ORD(D)-1) * XINCRQUANT(PX2,QX) ;
XQUANT(PX2,QX,D)    = XQUANTO(PX2,QX) + XQUANTR(PX2,QX,D) - XQUANTRO(PX2,QX) ;

XPRICE(PX2,QX,D)    = XPRICE0(PX2,QX) +
                   ((XQUANT(PX2,QX,D) - XQUANTO(PX2,QX)) * XPRICE0(PX2,QX))
                   /(EXPELAS(PX2,QX) * XQUANTO(PX2,QX)) ;

XQUANTREV(PX2,QX,D)$(XPRICE(PX2,QX,D) GT 0) = XQUANTR(PX2,QX,D) +
                   (XQUANT(PX2,QX,D) - XQUANTR(PX2,QX,D)) +
                   XSUPELAS(PX2,QX) *
                   (XQUANTO(PX2,QX) - XQUANTRO(PX2,QX)) *
                   (XPRICE(PX2,QX,D) - XPRICE0(PX2,QX))/XPRICE0(PX2,QX) ;
XREGSHREV(PX2,QX,D)$(XQUANTREV(PX2,QX,D) GT 0 ) =
                   XQUANTR(PX2,QX,D)/XQUANTREV(PX2,QX,D) ;

XELASREV(PX2,QX,D)$(1-XREGSHREV(PX2,QX,D) GT 0 AND XREGSHREV(PX2,QX,D) GT 0) =
                   EXPELAS(PX2,QX)/XREGSHREV(PX2,QX,D)
             - XSUPELAS(PX2,QX) * (1-XREGSHREV(PX2,QX,D))/XREGSHREV(PX2,QX,D) ;

XPRICEREV(PX2,QX,D) = XPRICE0(PX2,QX) ;
XPRICEREV(PX2,QX,D)$(XQUANT(PX2,QX,D) LT XQUANTO(PX2,QX) AND XELASREV(PX2,QX,D) LT 0) =
                   XPRICE(PX2,QX,D+1) +
          ((XQUANTR(PX2,QX,D) - XQUANTR(PX2,QX,D+1)) * XPRICEREV(PX2,QX,D+1)) /
                   (XELASREV(PX2,QX,D) * XQUANTR(PX2,QX,D+1)) ;
XPRICEREV(PX2,QX,D)$(XQUANT(PX2,QX,D) GE XQUANTO(PX2,QX) AND XELASREV(PX2,QX,D) LT 0) =
                   XPRICE(PX2,QX,D-1) +
          ((XQUANTR(PX2,QX,D) - XQUANTR(PX2,QX,D-1)) * XPRICEREV(PX2,QX,D-1)) /
                   (XELASREV(PX2,QX,D) * XQUANTR(PX2,QX,D-1)) ;
XPRICEREV(PX2,QX,D)$(XELASREV(PX2,QX,D) EQ 0) = 0 ;

XBETAR(PX2,QX,D)$(XELASREV(PX2,QX,D) LT 0 AND XQUANTR(PX2,QX,D) GT 0) =
                   - XPRICEREV(PX2,QX,D) / (XELASREV(PX2,QX,D) * XQUANTR(PX2,QX,D)) ;
XALPHAR(PX2,QX,D)$(XELASREV(PX2,QX,D) LT 0 AND XQUANTR(PX2,QX,D) GT 0) =
                   XPRICEREV(PX2,QX,D) + XBETAR(PX2,QX,D) * XQUANTR(PX2,QX,D) ;

XOMEGAR(PX2,QX,D)   = XALPHAR(PX2,QX,D) * XQUANTR(PX2,QX,D)
                   - 0.5 * XBETAR(PX2,QX,D) * SQR(XQUANTR(PX2,QX,D)) ;
XRHOR(PX2,QX,D)     = XALPHAR(PX2,QX,D) * XQUANTR(PX2,QX,D)
                   - XBETAR(PX2,QX,D) * SQR(XQUANTR(PX2,QX,D)) ;


* -----------------------------------------------------------------------
* 2.3 DISPLAY CALCULATED PARAMETERS
* -----------------------------------------------------------------------

DISPLAY

YIELDAL_E3, YIELDAL, YIELDAH_E3, YIELDAH,
PRICEX_E3, PRICEX, PRICED_E3, PRICED,
XPRICE0_E3, XPRICE0, DPRICE0_E3, DPRICE0,
*PRICEI_E3, PRICEI,
```

```
DQUANTI_E3, DQUANTI, XQUANTI_E3, XQUANTI
PRLTRAN_E3, PRLTRAN, PRHTRAN_E3, PRHTRAN, OBJCOST_E3, OBJCOST,
COSTAL_E3, COSTAL,
COSTAH_E3, COSTAH, COSTAP_E3, COSTAP, COSTAF_E3, COSTAF,
LWCINP_E3, LWCINP,
LABAL_A, LABAL, LABAH_A, LABAH, LABAP_A, LABAP, LABAF_A, LABAF,
SUSTL_A, SUSTL, SUSTP_A, SUSTP
;

DISPLAY DISCRATE, DISCFACTY, ANNUFACT ;

DISPLAY EMPLOYFRAC, LAB_RRP, HLAB_RRMXE, HLAB_RRMXY, PLAB_RRMXY, ALAB_RRMXY, HLAB_RRMX,
        SLAB_RRMX ;

DISPLAY WAGERES, LABOUTP, LABOUTI, LABOUTEND, LABOUTY,
        PLABOUTY, ALABOUTY ;

DISPLAY LABNATPERS, LABNATP, LABNATI, LABNATEND, LABNATY, PLABNATY, ALABNATY, LABNAT0
        LABNATLIM, LABNATREV, LABSHARE, NAZLABELAS, INTWAGEREV, WAGEREV ;

DISPLAY WAGEMIN, WAGE0, WAGE, LABDEMELAS, LABSUPELAS,
        BETALAB2, ALPHALAB2
        LFACTLO, LFACTUP, LABOUT0, LABOUTLO, LABOUTUP, LABOUTINCR, LABNOF
        SQUARE, TRIANGLE, LABOMEGA ;

DISPLAY LABTRAN_A, LABTRAN, OUTTRAN_A, OUTTRAN ;

DISPLAY DPOPULATP, DINCELAS, DINCOMEP, DQUANTP,
        DQUANTEND, DQUANTY, DPQUANTY, DAQUANTY,
        DQUANT0, DQUANTR0, DQUANTRMIN, DQUANTRMAX, DINCRQUANT, DQUANTR, DQUANT,
        DPRICE, DQUANTREV, DREGSHREV, DELASREV, DPRICEREV
        DBETAR, DALPHAR, DOMEGAR, DRHOR;

DISPLAY XPOPULATP, XINCOMEP, XINCELAS, XQUANTP,
        XQUANTEND, XQUANTY, XPQUANTY, XAQUANTY,
        XQUANT0, XQUANTR0, XQUANTRMIN, XQUANTRMAX, XINCRQUANT, XQUANTR, XQUANT,
        XPRICE, XQUANTREV, XREGSHREV, XELASREV, XPRICEREV
        XBETAR, XALPHAR, XOMEGAR, XRHOR;


* -----------------------------------------------------------------------
* 2.4 BOUNDS ON VARIABLES
* -----------------------------------------------------------------------

* Teak
vDOMDEM.UP("TG",Q) = 0 ;
vEXPDEM.UP("TG",Q) = 0 ;
* Melina
vDOMDEM.UP("GA",Q) = 0 ;
vEXPDEM.UP("GA",Q) = 0 ;
* rice
vDOMDEM.UP("OS",Q) = 0 ;
vEXPDEM.UP("OS",Q) = 0 ;

$ONTEXT
vLUST.UP(R,S,C,TL,TY)$(SUSTL(S,C,TL,TY,"NBAL") GT 0 ) = 0 ;
vLUST.UP(R,S,C,TL,TY)$(SUSTL(S,C,TL,TY,"PBAL") GT 0 ) = 0 ;
vLUST.UP(R,S,C,TL,TY)$(SUSTL(S,C,TL,TY,"KBAL") GT 0 ) = 0 ;
vPAST.UP(R,S,P,SR)$(SUSTP(S,P,SR,"NBAL") GT 0 ) = 0 ;
vPAST.UP(R,S,P,SR)$(SUSTP(S,P,SR,"PBAL") GT 0 ) = 0 ;
vPAST.UP(R,S,P,SR)$(SUSTP(S,P,SR,"KBAL") GT 0 ) = 0 ;
$OFFTEXT


*=======================================================================*
*                3. SOLVE MODEL STATEMENTS                              *
*=======================================================================*

OPTION RESLIM = 100000 ;
OPTION ITERLIM = 100000 ;
OPTION LP = MINOS5 ;


* -----------------------------------------------------------------------
* 3_a. SOME EXTRA SOLVE MODEL STATEMENTS
* -----------------------------------------------------------------------

* necessary re-solving of model in case two non-adjacent labour supply
* segmentation variables vLYR are positive (in that case the 'in-between' vLYR
* variables are zero, but with positive reduced costs (marginals),
```

```
* which is contrary to LP theory.
* it is a successfull approach to 'solve' above mentioned problem of selection of two
* non-adjacent vLYR variabes.

set XXX /XXX1*XXX100/;

scalar stop /0/;

parameter xlsx(LS);
xlsx(ls)=1;

loop(xxx $(stop=0),
   vlyr.up(LS)=xlsx(ls);
   SOLVE REALM USING LP MAXIMIZE vZ  ;

   xlsx(ls)$(vlyr.m(ls)<0)=0;
   xlsx(ls)$((vlyr.m(ls)=0)and((vlyr.m(ls+1)>0)or(vlyr.m(ls-1)>0)))=0;
   stop=1$(sum(ls,xlsx(ls))<=2);
);


*==================================================================*
*  4. REPORTING                                                    *
*==================================================================*

* Some extra parameters and variables
PARAMETER SOIL_MX     soil availability in AZ;
PARAMETER SOIL_SMX(S) soil availability in AZ per soil type;

* parameters for calculating total transport costs
PARAMETER CROP_TRANS ;
PARAMETER ANIM_TRANS ;

* assignments
CROP_TRANS =   SUM((R,C,Q), PRLTRAN(R,C,Q) * vPRODLR.L(C,Q,R)) ;
ANIM_TRANS =   SUM((R,HP,Q), PRHTRAN(R,HP,Q) * vPRODHR.L(HP,Q,R)) ;

DISPLAY
vPRODLR.L, vPRODHR.L
CROP_TRANS, ANIM_TRANS
vINPUTS.L

DISPLAY PRETAXLUST, PREMLUST
;

VARIABLES
vZSCALED       scaled variable cZ divided by 1000000000
vLANDLRSM(R)   Total land used by LUSTS per region
vLANDLSSM(S)   Total land used by LUSTS per soil
vLANDLSM       total land used by LUST
vLANDPRSM(R)   total land used by PASTOs per region
vLANDPSSM(S)   total land used by PASTOs per soil
vLANDPSM       total land used by PASTOs
vLSSMPER(S)    percentage land LUST used per soil type
vPSSMPER(S)    percentage land PASTO used per soil type
vUNUSED        total unused land in the AZ
;

* After optimisation assignments and calculations
vCROPT_NAZ.L(C,TL,TY) = SUM((R,S)$LP(S,C,TL,TY), vLUST.L(R,S,C,TL,TY)) ;
vLUSTS.L(S,C,TL,TY)   = SUM((R)$LP(S,C,TL,TY), vLUST.L(R,S,C,TL,TY)) ;
vGRASS_NAZ.L(P,SR)    = SUM((R,S)$PP(S,P,SR), vPAST.L(R,S,P,SR)) ;
vPASTS.L(S,P,SR)      = SUM((R)$PP(S,P,SR), vPAST.L(R,S,P,SR)) ;
vAPST_NAZ.L(H)        = SUM((R), vAPST.L(R,H)) ;
vSFED_NAZ.L(F)        = SUM((R,SE), vSFEDSE.L(R,F,SE)) ;
vSFEDSE_NZ.L(F,SE)    = SUM((R), vSFEDSE.L(R,F,SE)) ;
vZSCALED.L            = vZ.L/1000000000 ;
vLANDLRSM.L(R)        = SUM((S,C,TL,TY),vLUST.L(R,S,C,TL,TY)) ;
vLANDLSSM.L(S)        = SUM((R,C,TL,TY),vLUST.L(R,S,C,TL,TY)) ;
vLANDLSM.L            = SUM((R,S,C,TL,TY),vLUST.L(R,S,C,TL,TY)) ;
vLANDPRSM.L(R)        = SUM((S,P,SR), vPAST.L(R,S,P,SR)) ;
vLANDPSSM.L(S)        = SUM((R,P,SR), vPAST.L(R,S,P,SR)) ;
vLANDPSM.L            = SUM((R,S,P,SR), vPAST.L(R,S,P,SR)) ;
SOIL_MX               = SUM((R,S),SOIL_RSMX(R,S)) ;
SOIL_SMX(S)           = SUM((R),SOIL_RSMX(R,S)) ;
vLSSMPER.L(S)         = 100*vLANDLSSM.L(S)/SOIL_SMX(S) ;
vPSSMPER.L(S)         = 100*vLANDPSSM.L(S)/SOIL_SMX(S) ;
vUNUSED.L             = SOIL_MX - vLANDLSM.L - vLANDPSM.L ;
```

```
* ------------------------------------------------------------
*      SOME SAVE STATEMENTS FOR RESULTS BASE RUN SCENARIO
* ------------------------------------------------------------

SCALAR BBENEFIT          benefits (added value);
SCALAR BLUSTS            total LUST land use ;
SCALAR BPASTS            total past land use ;
SCALAR BLUNUSED          total unused land ;
SCALAR BNAZLAB           total NAZ labour use ;
SCALAR BOLAB             total outside labour use ;
SCALAR BANIMALS          total number of animals ;
PARAMETER BCROPS(C)      total acreages of crops ;
PARAMETER BBSUST(SU)     total sustainability parameters realized ;

BBENEFIT    = vZSCALED.L ;
BLUSTS      = vLANDLSM.L ;
BPASTS      = vLANDPSM.L ;
BLUNUSED    = vUNUSED.L ;
BNAZLAB     = vLABFARMYR.L ;
BOLAB       = vLABOUTYR.L ;
BCROPS(C)   = SUM((S,TL,TY),vLUSTS.L(S,C,TL,TY)) ;
BANIMALS    = SUM((R,H),vAPST.L(R,H)*HSIZE(H)) ;
BBSUST(SU)  = vSUST.L(SU) ;


* ---------------------------------------------------------------------
* 4.1 OUTPUT WRITING 1
* ---------------------------------------------------------------------

FILE RES /RESULTS.DAT/;

PUT RES '*************************************************' /;
PUT RES '* SUMMARY OUTPUT OPTIMIZATION MODEL REALM       *' /;
PUT RES '* RESULTS OF BASE RUN                           *' /;
PUT RES '*************************************************' /;
PUT RES '                            ' /;
PUT RES '*************************************************' /;
PUT RES '*     OBJECTIVE FUNCTION                        *' /;
PUT RES '*************************************************' /;
PUT RES 'Total benefits in 10EXP9 colon/year' /;
PUT RES 'Benefits = ', vZSCALED.L:20:3 / ;
PUT RES '                            ' /;
PUT RES 'Total benefits in 10EXP6 DOLAR/year' /;
PUT RES 'Benefits = ', (1000*vZSCALED.L/DOLAR):20:3 / ;

PUT RES '                            ' /;
PUT RES '                            ' /;
PUT RES '*************************************************' /;
PUT RES '*        RESOURCES USED                         *' /;
PUT RES '*************************************************' /;
PUT RES 'Total land use in AZ in ha' /;
PUT RES 'Land used by road, rivier, city =',
             ((1-SOILREDUC)*(SOIL_MX/SOILREDUC)):20:3 /;
PUT RES 'Land available  for agriculture =', SOIL_MX:20:3 /;
PUT RES 'Land use LUSTs                  =', vLANDLSM.L:20:3 /;
PUT RES 'Land use PASTOs                 =', vLANDPSM.L:20.:3 /;
PUT RES 'Land not used                   =', vUNUSED.L:20.:3 /;
PUT RES '                            ' /;
PUT RES 'Total land use in AZ, per soil type in ha' /;
PUT RES 'Soil type          LUT          PASTO         Maximum'/ ;
LOOP((S),
  PUT S.TL:9, vLANDLSSM.L(S):15:2, vLANDPSSM.L(S):15:2,
            SOIL_SMX(S):15:2 /;
);
PUT RES '                            ' /;
PUT RES 'Total land use in AZ, per soil type in %' /;
PUT RES 'Soil type          LUT          PASTO         Maximum'/ ;
LOOP((S),
  PUT S.TL:9, vLSSMPER.L(S):15:2, vPSSMPER.L(S):15:2,
            SOIL_SMX(S):15:2 /;
);

PUT RES '                            ' /;
PUT RES 'Total land use in AZ, per sub-region in ha' /;
PUT RES 'Reg.       LUST    PAST     MAX  Banana'/ ;
LOOP((R),
   PUT R.TL:7, SUM((S,C,TL,TY),vLUST.L(R,S,C,TL,TY)):8:0,
   SUM((S,P,SR),vPAST.L(R,S,P,SR)):8:0,
   SUM((S),SOIL_RSMX(R,S)):8:0,
   SUM((S,TL,TY),vLUST.L(R,S,"MA",TL,TY)):8:0 /;
);
```

```
PUT RES '                     ' /;
PUT RES 'Labour use in days' /;
PUT RES 'NAZ Labor availability =', SUM((RR,M),LAB_RRMX(RR,M)):15:2 / ;
PUT RES 'NAZ Labor use          =', vLABFARMYR.L:15:2 / ;
PUT RES 'Outside labor use      =', vLABOUTYR.L:15:2 / ;

PUT RES '                     ' /;
PUT RES '                     ' /;
PUT RES 'Labour wage segment ' /;
PUT RES 'Segment  value' /;
LOOP((LS),
  IF(vLYR.L(LS) GT 0,
  PUT LS.TL:7, vLYR.L(LS):12:9 /;
     )
);

PUT RES '                     ' /;
PUT RES '                     ' /;
PUT RES '********************************************' /;
PUT RES '*       LAND USE                           *' /;
PUT RES '********************************************' /;
PUT RES 'Land use type distribution (ha)' /;
PUT RES 'Land use     ha ' / ;
LOOP((P),
  IF(SUM((S,SR),vPASTS.L(S,P,SR)) GT 0,
     PUT P.TL:10, SUM((S,SR),vPASTS.L(S,P,SR)):13:2 /;
     )
);
LOOP((C),
   PUT C.TL:10, SUM((S,TL,TY),vLUSTS.L(S,C,TL,TY)):13:2 /;
);

PUT RES '                     ' /;
PUT RES 'Pasture type distribution over soil types per ha' /;
PUT RES 'SOIL   PASTO       Stocking rate    Use  ' / ;
LOOP((S,P,SR),
  IF(vPASTS.L(S,P,SR) GT 0,
  PUT S.TL:7, P.TL:4, SR.TL:7, SRATE(S,P,SR):6:2,
      vPASTS.L(S,P,SR):20:2 /;
     )
);

PUT RES '                     ' /;
PUT RES 'LUST type distribution over soil types in ha' /;
PUT RES 'SOIL   LUT           Use  ' / ;
LOOP((S,C,TL,TY),
  IF(vLUSTS.L(S,C,TL,TY) GT 0,
   PUT S.TL:7, C.TL:3, TL.TL:5, TY.TL:3, vLUSTS.L(S,C,TL,TY):13:2 /;
  )
);

PUT RES '                     ' /;
PUT RES 'LUST type distribution over mechanisible soil types in ha' /;
PUT RES 'SOIL   LUT           Use  ' / ;
LOOP((S,C,TL,TY),
  IF(vLUSTS.L(S,C,TL,TY)$LM(S,C,TL,TY) GT 0,
   PUT S.TL:7, C.TL:3, TL.TL:5, TY.TL:3, vLUSTS.L(S,C,TL,TY):13:2 /;
  )
);

PUT RES '                     ' /;
PUT RES 'LUST distribution over soil types per sub-region in ha' /;
PUT RES 'SUB-REGION  SOIL   LUT            Use  ' / ;
LOOP((R,S,C,TL,TY),
  IF(vLUST.L(R,S,C,TL,TY) GT 0,
   PUT R.TL:12, S.TL:7, C.TL:3, TL.TL:5, TY.TL:3, vLUST.L(R,S,C,TL,TY):13:2 /;
  )
);

PUT RES '                     ' /;
PUT RES 'LUST distribution over mechanisible soil types per sub-region in ha' /;
PUT RES 'SUB-REGION  SOIL   LUT            Use  ' / ;
LOOP((R,S,C,TL,TY),
  IF(vLUST.L(R,S,C,TL,TY)$LM(S,C,TL,TY) GT 0,
   PUT R.TL:12, S.TL:7, C.TL:3, TL.TL:5, TY.TL:3, vLUST.L(R,S,C,TL,TY):13:2 /;
  )
);

PUT RES '                     ' /;
PUT RES 'PASTO distribution over soil types per sub-region in ha' /;
```

```
PUT RES 'SUB-REGION  SOIL   PASTO         Stocking rate    Use   ' / ;
LOOP((R,S,P,SR),
  IF(vPAST.L(R,S,P,SR) GT 0,
  PUT R.TL:12, S.TL:7, P.TL:4, SR.TL:7, SRATE(S,P,SR):6:2,
      vPAST.L(R,S,P,SR):20:2 /;
     )
);

PUT RES '                       ' /;
PUT RES '                       ' /;
PUT RES '**************************************************' /;
PUT RES '* SELECTED HERDS                                *' /;
PUT RES '**************************************************' /;
PUT RES 'Herds (APST) in number of herds' /;
PUT RES 'Herd           Number'/;
PUT RES '                       ' /;

LOOP((H),
  IF(SUM((R),vAPST.L(R,H)) GT 0,
     PUT H.TL:11, SUM((R),vAPST.L(R,H)):10:2 /;
   )
);

PUT RES '                       ' /;
PUT RES 'Herds (APST) in number of animal units' /;
PUT RES 'Herd           Number AU'/;
PUT RES '                       ' /;

LOOP((H),
  IF(SUM((R),vAPST.L(R,H)) GT 0,
     PUT H.TL:11, SUM((R),vAPST.L(R,H)*HSIZE(H)):10:2 /;
   )
);

PUT RES '                       ' /;
PUT RES '                       ' /;
PUT RES '**************************************************' /;
PUT RES '* SELECTED FEED SUPPLEMENTS                     *' /;
PUT RES '**************************************************' /;
$ONTEXT
PUT RES 'Feeds suplements (FAST) in kg' /;
PUT RES 'Feed type  Season           Solution '/;
PUT RES '                       ' /;

LOOP((F,SE),
  IF (vSFEDSE_NZ.L(F,SE) GT 0,
     PUT F.TL:11, SE.TL:11, vSFEDSE_NZ.L(F,SE):15:2 /;
  )
);
$OFFTEXT
PUT RES 'Feeds supplements (FAST) in kg and in kg/AU; DRY season' /;
PUT RES 'Feed type        Solution    Sol/AU'/;
PUT RES '                       ' /;

LOOP((F),
  IF(SUM((R,H),vAPST.L(R,H)) GT 0,
   PUT F.TL:11, vSFEDSE_NZ.L(F,"DRY"):15:2,
   (vSFEDSE_NZ.L(F,"DRY")/SUM((R,H),vAPST.L(R,H)*HSIZE(H)*93)):10:2 /;
   )
);
PUT RES '                       ' /;
PUT RES 'Feeds supplements (FAST) in kg and in kg/AU; WET season' /;
PUT RES 'Feed type        Solution    Sol/AU'/;
PUT RES '                       ' /;

LOOP((F),
 IF(SUM((R,H),vAPST.L(R,H)) GT 0,
  PUT F.TL:11, vSFEDSE_NZ.L(F,"WET"):15:2,
  (vSFEDSE_NZ.L(F,"WET")/SUM((R,H),vAPST.L(R,H)*HSIZE(H)*272)):10:2 /;
 )
);

PUT RES '                       ' /;
PUT RES '                       ' /;
PUT RES '**************************************************' /;
PUT RES '* SUSTAINABILITY INDICATORS                     *' /;
PUT RES '**************************************************' /;
PUT RES 'Sustainability indicators' /;
PUT RES 'Indicator       Solution                   Maximum'/ ;
PUT RES '                       ' /;
```

```
LOOP((SU),
      PUT SU.TL:9, vSUST.L(SU):15:0, SUST_MX(SU):25:0 /;
);

PUT RES '                       ' /;
PUT RES 'Indicator       Solution              Sol/hectare'/ ;
LOOP((SU),
      PUT SU.TL:9, vSUST.L(SU):15:0,
      (vSUST.L(SU)/(SOIL_MX-vUNUSED.L)):25:5 /;
);

PUT RES '                       ' /;
PUT RES '                       ' /;

PUT RES 'Reg.        NBAL      PBAL      KBAL      NDEN '/ ;
LOOP((R),
      PUT R.TL:7, vSUSTR.L(R,"NBAL"):10:0, vSUSTR.L(R,"PBAL"):10:0,
      vSUSTR.L(R,"KBAL"):10:0, vSUSTR.L(R,"NDEN"):10:0 /;
);
PUT RES '                       ' /;
PUT RES '                       ' /;

PUT RES 'Reg.        NLEA      NVOL      BIOA      BIOI '/ ;
LOOP((R),
      PUT R.TL:7, vSUSTR.L(R,"NLEA"):10:0, vSUSTR.L(R,"NVOL"):10:0,
      vSUSTR.L(R,"BIOA"):10:0, vSUSTR.L(R,"BIOI"):10:0 /;
);

PUT RES '                       ' /;
PUT RES '                       ' /;
PUT RES '*************************************************' /;
PUT RES '*    SHADOW PRICES LAND AND LABOUR              *' /;
PUT RES '*************************************************' /;
PUT RES 'Land shadow prices in C./ha' /;
PUT RES '                            Soil type '/ ;
PUT RES 'Sub-region          SFP             SFW            SIW'/ ;
LOOP((R),
  PUT R.TL:9, cLAND.M(R,"SFP"):15:2, cLAND.M(R,"SFW"):15:2,
              cLAND.M(R,"SIW"):15:2 /;
);

PUT RES '                       ' /;
PUT RES 'Shadow prices of mechanisible land in C./ha' /;
PUT RES '                            Soil type '/ ;
PUT RES 'Sub-region          SFP             SFW            SIW'/ ;
LOOP((R),
  PUT R.TL:9, cLANDMECH.M(R,"SFP"):15:2, cLANDMECH.M(R,"SFW"):15:2,
              cLANDMECH.M(R,"SIW"):15:2 /;
);

*new put statement, Bas and Andre, 12 February
PUT RES '                                '/ ;
PUT RES 'Total labour use (days), labour from same sub-region use (days) and ' /;
PUT RES 'availability (days) of agricultural labour from within sub-regions' /;
PUT RES '                                '/ ;
PUT RES 'Sub-region  Labuse in Sub-region    Labuse in NAZ    Available lab' /;
LOOP((R),
  PUT R.TL:10, SUM((RR), vLABTRANYR.L(R,RR)):22 :0,
  SUM((RR), vLABTRANYR.L(RR,R)):17:0, SUM(M, LAB_RRMX(R,M)):17:0 /;
);

* old put statement re-instated by Rob, 15 April 1998
PUT RES '                                '/ ;
PUT RES 'Use (days), availability (days) and shadow prices (C./day)' /;
PUT RES 'of agricultural labour from within sub-regions' /;
PUT RES '                                '/ ;
PUT RES 'Sub-region    Labuse in NAZ     Available lab  Schadow price' /;
LOOP((RR),
  PUT RR.TL:10, SUM((R), vLABTRANYR.L(R,RR)):15:0, SUM(M, LAB_RRMX(RR,M)):20:0,
               cLABONFRR.M(RR):15:2 /;
);

PUT RES '                       ' /;
PUT RES '                       ' /;
PUT RES '*************************************************' /;
PUT RES '*    PRODUCTION DOMESTIC AND EXPORT             *' /;
PUT RES '*************************************************' /;
PUT RES '                       ' /;
PUT RES 'Price segments products' /;
PUT RES '                       ' /;
PUT RES 'Domestic products' /;
```

```
PUT RES 'Segment   product        (vD)' /;
LOOP((PD,QD2,D),
  IF(vD.L(PD,QD2,D) GT 0,
         PUT D.TL:9, PD.TL:10, vD.L(PD,QD2,D):10:2 /;
     )
);
PUT RES '                         ' /;
PUT RES 'Export  products' /;
PUT RES 'Segment   product        (vX)' /;
LOOP((PX2,QX,D),
  IF(vX.L(PX2,QX,D) GT 0,
         PUT D.TL:9, PX2.TL:10, vX.L(PX2,QX,D):10:2 /;
     )
);

PUT RES '                         ' /;
PUT RES 'Demand for products (tons)' /;
PUT RES '                         ' /;
PUT RES 'Domestic products' /;
PUT RES 'Product  Quality    (DOMDEM)' /;
LOOP((PA,Q),
  IF(vDOMDEM.L(PA,Q) GT 0,
         PUT PA.TL:9, Q.TL:10, vDOMDEM.L(PA,Q):10:2 /;
     )
);
PUT RES '                         ' /;
PUT RES 'Export  products' /;
PUT RES 'Product  Quality    (EXPDEM)' /;
LOOP((PA,Q),
  IF(vEXPDEM.L(PA,Q) GT 0,
         PUT PA.TL:9, Q.TL:10, vEXPDEM.L(PA,Q):10:2 /;
     )
);


* -------------------------------------------------------------------
* 4.2 OUTPUT WRITING 2: GIS FILES
* -------------------------------------------------------------------

FILE RES1 /GISCROP.DAT/;

PUT RES1 '                         ' /;
PUT RES1 'LUST distribution over soil types per sub-region in ha' /;
PUT RES1 'REG     SOL    CROP    TECHN            USE  ' / ;
LOOP((R,S,C,TL,TY),
  IF(vLUST.L(R,S,C,TL,TY) GT 0,
   PUT RES1 R.TL:7,',', S.TL:5,',', C.TL:6,',', TL.TL:5, TY.TL:3,',',
       vLUST.L(R,S,C,TL,TY):13:2 /;
  )
);

FILE RES2 /GISPAST.DAT/;
PUT RES2 '                         ' /;
PUT RES2 'PAST distribution over soil types per sub-region in ha' /;
PUT RES2 'REG     SOL    PAST    SR           USE  ' / ;
LOOP((R,S,P,SR),
  IF(vPAST.L(R,S,P,SR) GT 0,
   PUT RES2 R.TL:7,',', S.TL:5,',', P.TL:6,',', SR.TL:5,',',
       vPAST.L(R,S,P,SR):13:2 /;
  )
);
```

Appendix 2. REALM data files

```
* REALM DATA FILES, EXCEPT FOR THE TECHNICAL COEFFICIENTS AS GENERATED BY PASTOR AND LUCTOR

* Read Tables concerning labour availability (RHS)
*  labour availability
PARAMETER
HLAB_RRMX(RR)
         /R111     13942
          R112      4409
          R121       363
          R211       183
          R212      3230
          R221     11485
          R2221     1817
          R2222      600
          R2223      250
          R9991     1781
          R9992      643
          R9993     1346/
;

* Tables concerning soil/land availability (RHS); ha per soil type per zone
* TABLE SOIL_RSMX(R,S), TABLE SOILM_RSMX(R,S)
TABLE SOIL_RSMX(R,S)

*$ONTEXT
* Land availability: only not-protected areas
            SFW     SFP     SIW
R111      63437   19711   26365
R112       9666   14516    7263
R121       1493    1642     812
R211        276     818     726
R212       6521   15991   10384
R221      11047   41838    9257
R2221      2662    4004    3432
R2222       563    3552     141
R2223       667       0     950
R9991      4553   13504     565
R9992       391     107      33
R9993      1748       0     265
*$OFFTEXT

$ONTEXT
* land availability: not-protected areas & semi-protected:
* reservas indigenas, reservas forestales, zonas protectores & zonas de humedad
            SFW     SFP     SIW
R111      64076   19711   29024
R112       9666   14516    7263
R121       1493    1642     878
R211        276     818     726
R212       6546   16001   10430
R221      12243   41838   11278
R2221      4340    7967   10981
R2222       563    3552     141
R2223       667       0     950
R9991     10864   25350    5514
R9992       647     119    1331
R9993      4145       0    2058
$OFFTEXT

$ONTEXT
* land availability: whole area of NAZ; includes semi-protected areas and
* protected areas, the natural parks
            SFW     SFP     SIW
R111      64136   19711   29469
R112       9666   14516    7263
R121       1493    1642     878
R211        276     818     726
R212       6601   16315   10789
R221      12243   41838   11278
R2221      4505    8360   10996
R2222       563    3552     141
R2223       667       0     950
R9991     13101   29098    9450
R9992       647     119    1331
R9993      4536       0    2437
$OFFTEXT
;
```

```
* Land available for mechanisation
TABLE SOILM_RSMX(R,S)

*$ONTEXT
* Land available for mechanisation: only not protected areas
         SFW      SFP      SIW
R111      43493    18097    20327
R112       9564    14516     6286
R121       1233     1519        0
R211          0      818      726
R212       6521    15991     8058
R221       7115    41646     3099
R2221      2662     4004     2301
R2222       563     3552      141
R2223        17        0        0
R9991      4553    13504      429
R9992       261      107        0
R9993       103        0      155
*$OFFTEXT

$ONTEXT
* land available for mechnisation: not-protected and semi protected areas
         SFW      SFP      SIW
R111      43534    18097    22364
R112       9564    14516     6286
R121       1233     1519        0
R211          0      818      726
R212       6546    16001     8075
R221       7227    41646     3693
R2221      4340     7967     5318
R2222       563     3552      141
R2223        17        0        0
R9991     10864    25350     2487
R9992       445      119      167
R9993       103        0     1015
$OFFTEXT

$ONTEXT
* land available for mechanisation: whole area of NAZ; includes semi-protected
* areas and protected areas, the natural parks
         SFW      SFP      SIW
R111      43552    18097    22809
R112       9564    14516     6286
R121       1233     1519        0
R211          0      818      726
R212       6601    16315     8089
R221       7227    41646     3693
R2221      4505     8360     5333
R2222       563     3552      141
R2223        17        0        0
R9991     13101    29098     3277
R9992       445      119      167
R9993       108        0     1394
$OFFTEXT
;

* Tables concerning premiums and taxes on LUTs ans PASs
* PRETAXLUST(C), PRETAXPAST(P)
PARAMETER PRETAXLUST(C)
             /AC  0
              AM  0
              BG  0
              GA  0
              SN  0
              OS  0
              MA  0
              MB  0
              ME  0
              PV  0
              TG  0
              ZM  0
              ZC  0/
;

*UPDATED WITH PRICES ON RICE AND NATURAL FOREST PRODUCTS, 17 FEB. 1998
* NEW TEAK PRICES, NIEUWENHUYSE APRIL 1998

* Tables concerning product prices, markets and elasticities
* Tables PRICEX_E3(PX1,QX), PRICED_E3(PD,QD1)
* DINCELAS(PD,QD2), DOMELAS(PD,QD2), DQUANTI_E3(PD,QD2), DPRICE0_E3(PD,QD2)
* DREGSHARE(PD,QD2), DFACTMIN(PD,QD2), DFACTMAX(PD,QD2), DSUPELAS(PD,QD2)
```

```
* XPOPULATP(PX2,QX), XINCOMEP(PX2,QX), XINCELAS(PX2,QX), XFACTMIN(PX2,QX)
* XFACTMAX(PX2,QX), EXPELAS(PX2,QX), XQUANTI_E3(PX2,QX), XPRICE0_E3(PX2,QX)
* XNATSHARE(PX2,QX), XREGSHARE(PX2,QX), XSUPELAS(PX2,QX)

* Prices (no market constraint)
TABLE
PRICEX_E3(PX1,QX)
         EXP
GA      4670
SN      6283
OS        54
PV       101
TG     28020
ZM        36
LWCY     176
LWCO     136
LWEY     165
LWDY     152
MLK       50
;

TABLE PRICED_E3(PD,QD1)
         DOM         REF
AM
BG
GA      4670
SN      6283
OS        54
MA
MB
ME
PV
TG      28020          0
ZM
ZC
LWCY     176
LWCO     136
LWEY
LWDY     152
MLK
;




* Elasticities
TABLE DINCELAS(PD,QD2)
         DOM
AM       0.2
BG       0.4
MA       0.2
MB       0.2
ME       0.1
PV       0.2
ZM       0.3
ZC       0.4
LWEY     0.6
MLK      0.6
;

TABLE DOMELAS(PD,QD2)
         DOM
AM      -0.7
BG      -1.2
MA      -0.7
MB      -0.8
ME      -0.6
PV      -0.9
ZM      -0.9
ZC      -1.0
LWEY    -0.9
MLK     -0.9
;
```

```
* In kg: divide by 1000 to get ton
TABLE DQUANTI_E3(PD,QD2)
                   DOM
AM          16800000
BG           2000000
MA          30600000
MB          38200000
ME          14300000
PV          28300000
ZM         254300000
ZC           3400000
LWEY        68100000
MLK        483400000
;

* In colon per kg: multiply by 1000 to get colon per ton
TABLE DPRICE0_E3(PD,QD2)
              DOM
AM             41
BG             36
MA             15
MB             34
ME             32
PV            101
ZM             36
ZC             38
LWEY          165
MLK            50
;

TABLE DREGSHARE(PD,QD2)
             DOM
AM       0.003
BG       0.5
MA       0.67
MB       0.1
ME       0.003
PV       0.005
ZM       0.004
ZC       0.004
LWEY     0.2
MLK      0.0005
;

TABLE DFACTMIN(PD,QD2)
             DOM
AM             3
BG             3
MA             3
MB             3
ME             3
PV             3
ZM             3
ZC             3
LWEY           3
MLK            3
;

TABLE DFACTMAX(PD,QD2)
             DOM
AM           100
BG             3
MA             3
MB             3
ME           100
PV             3
ZM             3
ZC           100
LWEY           3
MLK            3
;
```

```
 TABLE DSUPELAS(PD,QD2)
          DOM
 AM        0.7
 BG        0.7
 MA        0.7
 MB        0.7
 ME        0.7
 PV        0.7
 ZM        0.7
 ZC        0.7
 LWEY      0.7
 MLK       0.7
 ;

* Export market calculations
TABLE XPOPULATP(PX2,QX)
          EXP
AC      0.007
BG      0.009
MA      0.007
MB      0.020
ME      0.020
;

TABLE XINCOMEP(PX2,QX)
          EXP
AC      0.015
BG      0.013
MA      0.015
MB      0.013
ME      0.013
;

TABLE XINCELAS(PX2,QX)
          EXP
AC        1.1
BG        1.8
MA        0.5
MB        1.2
ME        0.9
;

TABLE XFACTMIN(PX2,QX)
          EXP
AC          3
BG          3
MA          3
MB          3
ME          3
;

TABLE XFACTMAX(PX2,QX)
          EXP
AC         50
BG         20
MA          5
MB         50
ME         50
;

TABLE EXPELAS(PX2,QX)
          EXP
AC       -1.1
BG       -1.8
MA       -0.5
MB       -1.2
ME       -0.9
;

* in kg: divide by 1000 to get ton
TABLE XQUANTI_E3(PX2,QX)
                 EXP
AC         768222000
BG         106400000
MA       13355660000
MB          81300000
ME         224629000
;
```

```
* In colon per kg: multiply by 1000 to get colon per ton
TABLE XPRICE0_E3(PX2,QX)
         EXP
AC        46
BG        47
MA        53
MB        57
ME        64
;

TABLE XNATSHARE(PX2,QX)
         EXP
AC       0.22
BG       0.20
MA       0.15
MB       0.20
ME       0.67
;

TABLE XREGSHARE(PX2,QX)
         EXP
AC       0.025
BG       0.50
MA       0.67
MB       0.10
ME       0.01
;

TABLE XSUPELAS(PX2,QX)
         EXP
AC        0.7
BG        0.7
MA        0.7
MB        0.7
ME        0.7
;
* Tables concerning scaling factors and other scalars
* SCALEFACT, DISCRATE, OBJCOST_E3, DPOPULATP, DINCOMEP, WAGE_P, DOLAR
* LAB_RRP, LABOUTP, LABNATP, LABNAZFACT, EMPLOYFRAC, LABNATPERS, LABSUPE, LABDEME
* TRIPDAY, SOILREDUC, DLRCHAN, TRSINFL

* Dollar rate (colones/US$ average 1994-1996)
SCALAR  DOLAR           /180.97/ ;

* Domestic demand calculations: population growth and income per capita growth per year
SCALAR  DPOPULATP            /0.02/ ;
SCALAR  DINCOMEP             /0.028/ ;

* Costs of agricultural activities
SCALAR  OBJCOST_E3           /1/ ;

* Scaling factor
SCALAR  SCALEFACT          /1000/;

* Discount rate
SCALAR  DISCRATE             /0.07/ ;

* NAZ labour availability as fraction of estimated availability
SCALAR  LABNAZFACT           /1.00/ ;
* NAZ employment fraction of estimated labour availability
SCALAR  EMPLOYFRAC           /0.92/ ;
* National labour availability of relevant labour types
SCALAR  LABNATPERS         /735001/ ;
* Assumed national labour supply elasticity
SCALAR  LABSUPE              /0.2/ ;
* Assumed national labour demand elasticity
SCALAR  LABDEME              /-0.5/ ;
* Assumed growth of wage per year
SCALAR  WAGE_P               /0.000/ ;
* Lower limit of labour supply function to be segmented
SCALAR  LFACTLO              /0.7/ ;
* Upper limit of labour supply function to be segmented
SCALAR  LFACTUP              /1.2/ ;
* Annual growth of NAZ labour supply
SCALAR  LAB_RRP              /-0.00/ ;
* Annual growth of outside NAZ labour supply
SCALAR  LABOUTP              /-0.00/ ;
* Annual growth of national labour supply (of 'relevant types')
SCALAR  LABNATP              /0.02/ ;
* number of trips per week for labour 'from another sub-region' or from outside NAZ
SCALAR  TRIPDAY              /0.166667/ ;
```

```
* Reduction factor of available land due to roads, rivers and cities (-)
SCALAR SOILREDUC / 0.9 / ;

* Revalue average 1994-1995-1996 dollar exchange rate to 1996 level
SCALAR DLRCHAN  / 1.1455 / ;

* Specific inflation rate transport costs 1995-1996
SCALAR TRSINFL  / 1.1696 / ;

* Read Tables concerning permissible sustainability effects
TABLE HSUST_RSMX(S,SU)
      NBAL   PBAL   KBAL   NDEN   NLEA   NVOL   BIOA      BIOI
SFW  10000  10000  10000  10000  10000  10000  10000  10000000
SFP  10000  10000  10000  10000  10000  10000  10000  10000000
SIW  10000  10000  10000  10000  10000  10000  10000  10000000
;

* Convert nbal, pbal and kbal losses as negative figures into
* positive figures
PARAMETER CON_NPKBAL(SU)
     /NBAL     -1
      PBAL     -1
      KBAL     -1
      NDEN      1
      NLEA      1
      NVOL      1
      BIOA      1
      BIOI      1/
;

*Tables concerning transport prices (29 okt, 1997)
* Tables PRLTRAN_E3(R,C,Q),PRHTRAN_E3(R,HP,Q)

* transport costs crops (including fixed costs of C. 0.50 per kg)
TABLE PRLTRAN_E3(R,C,Q)
       AC.EXP  AM.DOM  BG.EXP BG.DOM  GA.EXP  GA.DOM  MA.EXP  MA.DOM  MB.EXP  MB.DOM  ME.EXP  ME.DOM  PV.EXP
PV.DOM  TG.EXP  TG.DOM  ZM.EXP  ZM.DOM  ZC.DOM  OS.EXP  OS.DOM   SN.EXP  SN.DOM
R111      0.8     6.6     2.5    6.6       0       0     0.8     6.6     3.0     6.6     3.0     6.6     3.0
6.6       0       0     3.0    6.6     6.6     3.0     6.6       0       0
R112      2.3     6.6     2.5    6.6     467     467     2.3     6.6     7.5     6.6     7.5     6.6     7.5
6.6    1168    1168     7.5    6.6     6.6     7.5     6.6     467     467
R121      0.8     6.6     2.5    6.6     467     467     0.8     6.6     3.0     6.6     3.0     6.6     3.0
6.6    1168    1168     3.0    6.6     6.6     3.0     6.6     467     467
R211      0.8     9.6     5.5    9.6     467     467     0.8     9.6     3.0     9.6     3.0     9.6     3.0
9.6    1168    1168     3.0    9.6     9.6     3.0     9.6     467     467
R212      2.3     9.6     5.5    9.6     934     934     2.3     9.6     7.5     9.6     7.5     9.6     7.5
9.6    2335    2335     7.5    9.6     9.6     7.5     9.6     934     934
R221      0.8     9.6     5.5    9.6       0       0     0.8     9.6     3.0     9.6     3.0     9.6     3.0
9.6       0       0     3.0    9.6     9.6     3.0     9.6     467     467
R2221     2.3     9.6     5.5    9.6    1401    1401     2.3     9.6     7.5     9.6     7.5     9.6     7.5
9.6    3504    3504     7.5    9.6     9.6     7.5     9.6     934     934
R2222     2.3     9.6     5.5    9.6    1401    1401     2.3     9.6     7.5     9.6     7.5     9.6     7.5
9.6    3504    3504     7.5    9.6     9.6     7.5     9.6     934     934
R2223     2.3     9.6     5.5    9.6    1401    1401     2.3     9.6     7.5     9.6     7.5     9.6     7.5
9.6    3504    3504     7.5    9.6     9.6     7.5     9.6     934     934
R9991     9.3    24.6    20.5   24.6    2335    2335     9.3    24.6    28.5    24.6    28.5    24.6    28.5
24.6   5840    5840    28.5   24.6    24.6    28.5    24.6     1868    1868
R9992     4.7    14.6    10.5   14.6    2335    2335     4.7    14.6    14.5    14.6    14.5    14.6    14.5
14.6   5840    5840    14.5   14.6    14.6    14.5    14.6     1868    1868
R9993     4.7    14.6    10.5   14.6    2335    2335     4.7    14.6    14.5    14.6    14.5    14.6    14.5
14.6   5840    5840    14.5   14.6    14.6    14.5    14.6     1868    1868
;

* transport costs animals (incluiding fixed costs of C. 357 per animal unit of 400 kg, or C. 0.893 per kg)
TABLE PRHTRAN_E3(R,HP,Q)
      LWCY.EXP  LWCY.DOM LWCO.EXP LWCO.DOM LWEY.EXP LWEY.DOM LWDY.EXP LWDY.DOM  MLK.EXP  MLK.DOM
R111     2.143     2.143    2.143    2.143    2.143    2.143    2.143    2.143       10       10
R112     2.143     2.143    2.143    2.143    2.143    2.143    2.143    2.143       10       10
R121     4.018     4.018    4.018    4.018    4.018    4.018    4.018    4.018       10       10
R211     2.143     2.143    2.143    2.143    2.143    2.143    2.143    2.143       15       15
R212     2.143     2.143    2.143    2.143    2.143    2.143    2.143    2.143       15       15
R221     4.018     4.018    4.018    4.018    4.018    4.018    4.018    4.018       15       15
R2221    4.018     4.018    4.018    4.018    4.018    4.018    4.018    4.018       15       15
R2222    4.018     4.018    4.018    4.018    4.018    4.018    4.018    4.018       15       15
R2223    4.018     4.018    4.018    4.018    4.018    4.018    4.018    4.018       15       15
R9991    7.143     7.143    7.143    7.143    7.143    7.143    7.143    7.143       60       60
R9992    5.580     5.580    5.580    5.580    5.580    5.580    5.580    5.580       45       45
R9993    5.580     5.580    5.580    5.580    5.580    5.580    5.580    5.580       45       45
;
* UPDATED VERSION, LABOUR MOBILITY COSTS, Nieuwenhuyse, feb. 1998
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* Tables concerning wages
* Parameters WAGERES(M), WAGEMIN(M), WAGEO(M), PERIODDAY(M), OUTTRAN_A(R)
* TABLE LABTRAN_A(RR,R)

* Labour market and availability calculations
PARAMETERS
* in colon per day: multiplied 8 * 200
  WAGERES(M)
                        /JAN     1600
                         FEB     1600
                         MAR     1600
                         APR     1600
                         MAY     1600
                         JUN     1600
                         JUL     1600
                         AUG     1600
                         SEP     1600
                         OCT     1600
                         NOV     1600
                         DEC     1600/

* In colon per day: multiplied 8 * 200
  WAGEMIN(M)
                        /JAN     1600
                         FEB     1600
                         MAR     1600
                         APR     1600
                         MAY     1600
                         JUN     1600
                         JUL     1600
                         AUG     1600
                         SEP     1600
                         OCT     1600
                         NOV     1600
                         DEC     1600/
* In colon per day: multiplied 8 * 200
  WAGEO(M)
                        /JAN     1600
                         FEB     1600
                         MAR     1600
                         APR     1600
                         MAY     1600
                         JUN     1600
                         JUL     1600
                         AUG     1600
                         SEP     1600
                         OCT     1600
                         NOV     1600
                         DEC     1600/

* Work days per month
  PERIODDAY(M)
                        /JAN       25
                         FEB       25
                         MAR       25
                         APR       25
                         MAY       25
                         JUN       25
                         JUL       25
                         AUG       25
                         SEP       25
                         OCT       25
                         NOV       25
                         DEC       25/

* In colon per day
  OUTTRAN_A(R)
                        /R111     390
                         R112     565
                         R121     465
                         R211     626
                         R212     640
                         R221     500
                         R2221    750
                         R2222    640
                         R2223    560
                         R9991   1500
                         R9992   1280
                         R9993   1120/
;
```

```
* In colon per day:
TABLE LABTRAN_A(RR,R) transaction costs of labour working in sub-region R coming
*                  from sub-region RR based on 1996 bus fares

          R111  R112  R121  R211  R212  R221  R2221 R2222 R2223 R9991 R9992 R9993
R111       120   130   140   205   235   175    280   320   140   500   500   500
R112       130    35   445   510    50   455    100   525   445   300   400   600
R121       140   445    35   345   485    75    580   360   280   600   200   400
R211       205   510   345    35   550   365    645   425   300   700   400   500
R212       235    50   485   550    35   495     60   565   485   200   500   600
R221       175   455    75   365   495    75    600   380   300   800   100   500
R2221      280   100   580   645    60   600     50   660   580   100   700   600
R2222      320   525   360   425   565   380    660    50   360   850   300   550
R2223      140   445   280   300   485   300    580   360    35   900   200   300
R9991      500   300   600   700   200   800    100   850   900   100   950   900
R9992      500   400   200   400   500   100    700   300   200   950    50   300
R9993      500   600   400   500   600   500    600   550   300   900   300    50

* In colon per day:
*TABLE LABTRAN_A(RR,R) transaction costs of labour working in sub-region R coming
*                  from sub-region RR based on 1996 bus fares
*
*         R111  R112  R121  R211  R212  R221  R2221 R2222 R2223 R9991 R9992 R9993
*R111        0   130   140   205   235   175    280   320   140   500   500   500
*R112      130     0   445   510    50   455    100   525   445   300   400   600
*R121      140   445     0   345   485    75    580   360   280   600   200   400
*R211      205   510   345     0   550   365    645   425   300   700   400   500
*R212      235    50   485   550     0   495     60   565   485   200   500   600
*R221      175   455    75   365   495     0    600   380   300   800   100   500
*R2221     280   100   580   645    60   600      0   660   580   100   700   600
*R2222     320   525   360   425   565   380    660     0   360   850   300   550
*R2223     140   445   280   300   485   300    580   360     0   900   200   300
*R9991     500   300   600   700   200   800    100   850   900     0   950   900
*R9992     500   400   200   400   500   100    700   300   200   950     0   300
*R9993     500   600   400   500   600   500    600   550   300   900   300     0
*R000      390   565   465   625   640   500    750   640   560  1500  1280  1120
;
```