The Consequences of Past Agricultural Outputs on the Interacting Nutrition and Health of Autarkic Peasants: Evidence From Rwanda

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ABSTRACT: In rural areas of LDCs, because of the existence of market imperfections, health and nutrition status may depend on the levels of specific agricultural productions and not only on the income level. However, these specific impacts have never been studied. We estimate, from a sequential technological model incorporating interactions between health and nutrition, changes in health and nutrition status of autarkic agricultural households in Rwanda which are due to variations in socio-demographic characteristics and in levels of specific crops. The model is supported by several tests. The estimations take into account cluster-fixed effects and the sampling scheme. The food outputs have generally beneficial influences on health and nutrition, while the traditional beers output has a negative impact. A policy based on incentives for substituting cultures may be particularly favourable to the health and nutrition of peasants.

RÉSUMÉ

Dans les zones rurales des pays en voie de développement, les états sanitaires et nutritionnels dépendent étroitement des niveaux de productions agricoles spécifiques, et pas seulement du niveau des revenus, en raison de l'existence d'imperfections de marchés. Cependant, ces impacts n'ont jamais été étudiés.

Nous estimons, à partir d'un modèle technologique séquentiel incorporant des interactions entre santé et nutrition, les changements de la santé et de la nutrition des ménages agricoles autarciques du Rwanda, dus aux variations de facteurs socio-démographiques exogènes, mais également à des variations des niveaux de récoltes spécifiques. Le modèle est supporté par plusieurs tests. Les estimations tiennent compte d'effets fixes pour les grappes et du plan de sondage.

Les productions alimentaires ont des effets généralement bénéfiques sur la santé et la nutrition, alors que la production de bières traditionnelles a un impact négatif. Une politique basée sur des incitations à substituer des cultures pourrait être particulièrement favorable à la santé et la nutrition des paysans.

Contents

1. Introduction

The analysis of consequences of income fluctuations on the health and nutritional status (HN) of peasants has attracted a lot of interest in the economic development literature (see recently Smil 1986, Behrman and Deolalikar 1988, The World Bank 1986, 1993, Kochar 1995, Sahn 1995, Strauss and Thomas 1995). Indeed, low agricultural output and therefore low living standards imply serious nutrition and health problems for peasants. On the other hand, some authors (Behrman and Wolfe 1984) argue that the variability of aggregate income may have a weaker influence on nutritional demand than do schooling and variations of other individual characteristics. In that case, the effects of past agricultural productions may be of second order. Besides, when there exist market imperfections, the usual separation theorems do not apply, and the effects of the different agricultural outputs on HN may involve the composition of the production rather than only an aggregate income effect. From another perspective, nutritionists (Gupta et al. 1992) and health specialists (Tomkins 1994) show that different products bring different nutrients that have specific effects on HN. The health and nutrition knowledge is unlikely to be totally mastered by peasant households. There has been no investigation in the literature of the direct influence of the composition of agricultural production on HN.

The very poor peasants in LDCs often live in areas where many markets are absent or very imperfect. In rural Rwanda, peasants mostly consume their own agricultural output (see Muller 1989).[1] Moreover, since most households are scattered in the hills, their isolation entails that the residual monetary transactions can be considered as a specific production process, with transport and transaction costs, in which agricultural products are converted to other market goods.[2] Of course, markets and monetary transactions still exist, but might have a more limited impact on the living standards of poor peasants than the size and composition of agricultural output. The average auto-consumption rate (proportion of consumption coming from own production) in our national sample is above 66% and almost 80% when one considers only food consumption.

In this context, our modelling strategy is to consider that most of the consumption can be directly explained by the output levels.[3] This is motivated by the fact that the effects of prices perform through highly complicated mechanisms of missing and imperfect markets and are therefore difficult to describe with a linear budget constraint. The enumerators of the survey have noticed – and we have confirmed this element by visits to markets and agricultural households – that there exists substantial variability of prices for the same product at a given date and a given location.

[1] This is also the case in the very similar context of Burundi as described in Cochet (1993) and Sindayizeruka (1993).

[2] Von Braun, Haen and Blanken (1991) show that commercialisation may be more important in specific areas of Rwanda (the commune Giciye in their study; Rwanda has 143 communes). The sample of households studied by these authors covers an area where markets are much denser than in most of rural Rwanda. In the Von Braun et al. study, the share of food consumption of the households that is own-produced is 48% while it is 80% for the whole of rural Rwanda (from our own estimates from the National Budget–Consumption Survey 1983). The great majority of households in Giciye have substantial non-agricultural incomes with an off-farm income equal on average to 58% of total income, while for the whole of rural Rwanda, only one quarter of households regularly receive wages, and generally for a small amount. Our national sample corresponds to peasants very oriented to subsistence activities.

[3] This is a polar case at the opposite of budget constraints with perfect markets.

In this situation, the markets failure may be general and affect every good and factor.[4] Moreover, the coefficients of prices that we added to the estimated equations appear to be non significant (as we show in section 4.1 below). Finally, the elimination of markets from global interactions makes tractable the empirical analysis of the effects of composition of agricultural outputs on the HN status. All these points support the rejection of the perfect markets framework.

Several studies consider simultaneously agricultural outputs and HN (Rosenzweig and Schultz 1983, Pitt and Rosenzweig 1985, 1986, Deolalikar 1988), often in order to estimate agricultural technology or decisions. Pitt and Rosenzweig (1985, 1986) specify simultaneously the agricultural and health technologies. First, the individual health production functions describe how the health of each household member depends on: vectors of nutrients; non-food health inputs; characteristics of the member; labour of the household; household resources that affect health; and exogenous health endowment of the member. Second, the agricultural production function describes how agricultural outputs depend on agricultural inputs and HN. We focus in this article only on the first type of relationship.

The household behaviour is represented in Pitt and Rosenzweig's papers by the maximisation of a utility function that depends on vectors of health, leisure and consumption for every member, subject to technology and income constraints. This approach is related to agricultural household models (see Singh, Squire and Strauss 1986 for a thorough study of these models). When all markets of goods and outputs exist and are perfect, one can derive demand equations for the food (and the nutrients) allocated to every member; output supply equations; and demand functions for the health or nutritional status of every member. In these models, because consumer and firm decisions are separable, input prices and agricultural environment affect consumption decisions and health status only through a profit effect into the budget constraint. The effects of exogenous agricultural shocks on HN (for instance bad crops due to climatic alea) are also conveyed through an income effect in the budget constraint. The composition of production does not matter once the profit effect is included.

When there are imperfect or missing markets for inputs that enter both in preferences and technology (as leisure for example), consumption and production decisions are not separable (see Singh, Squire and Strauss 1986 and Benjamin 1992). For example, de Janvry, Fafchamps and Sadoulet (1991) analyse a model of agricultural household with market imperfections for some products which leads to the use of implicit prices instead of observed prices. This is also the approach followed by Jacoby (1993). In our case, because there is no market for health and for nutrition status, and because they enter as inputs in the agricultural production process and as arguments in preferences, the behaviour is not separable and nutrition and health status are directly linked to the level and composition of production. In any case, when the other markets exist and are perfect, the demands for HN can still be considered as determined by the prices vector (but now for all the goods), the characteristics of the members and of the environment, and the unearned income, and not directly linked to the levels of agricultural outputs that are nonetheless endogenous. However, this modelling strategy does not directly account for lagged interactions in HN and agricultural technology.

[4] De Janvry, Fafchamps and Sadoulet (1991) propose a model with missing markets but its estimation would necessitate the presence of perfect markets at least for some goods, which may not be the case in our context.

Unfortunately, there are situations where both markets of consumption goods and markets of agricultural outputs are missing or imperfect, since many poor peasants live quasi-autarky. There, consumption and HN demands do not depend on prices but on characteristics of household preferences; on characteristics of joint HN-agriculture technology; on levels of past allocations (so as to incorporate lagged effects in HN technology and because the markets do not clear the output stocks) and other exogenous variables. No close form can generally be derived in this framework for consumption and HN demand functions. Moreover, in contrast with the prices, exogenous variables that appear in HN demand functions may at the same time be originated from preferences and from several constraints. The interpretation of the effects of these exogenous variables is delicate. For example, an effect of the education of the head on the health of members can be explained by differences in tastes for differently educated heads or by differences in their productivities in HN or agricultural processes.[5] Therefore, we consider it safer to focus on analysis and estimation of the HN technology only.

A few examples illustrate typical health production functions estimated in the literature. Income, calories and health status have been found to be related to the nutritional status of children. Prices are more rarely significant. Most studies deal with children, which involves different biological mechanisms (related to growth) than for adults. Using data from Columbia, Heller and Drake (1979) find a significant interaction between health and nutritional status for children, and a significant impact of nutrient sources on nutritional status of children; Thomas, Strauss and Henriques (1990) find in Brazil significant and positive effects of income on child survival but not on child height; Bouis and Haddad (1989) find in the Philippines significant and negative effects of diarrhoea and fever on the weight-for-height of pre-school children; von Braun, Hotchkins and Immink (1989) find in Guatemala a significant effect of income per capita, although a non-significant effect of the share of income from export crops, on the weight-for-height of children aged 6–120 months; von Braun, Puetz and Webb (1989) find in Gambia no significant effects for diarrhoea nor for calories per adult-equivalent on the weight-for-height of children aged 7–120 months. Senauer and Garcia (1991) find in the Philippines that parents' wages and the prices of rice and cooking oil have significant effects on the weight-for-height of pre-school children. Finally, von Braun, de Haen and Blanken (1991) find, in a commune of Rwanda, significant effects of sickness and calories on the weight-for-height of children aged 6–72 months.

However, only a few authors provide results concerning adults. In these articles, the specification of technologies and independent variables are very varied. Using data from Indonesia (1985), Pitt and Rosenzweig (1986) estimate a household illness production function under linear form, in which household work and twelve types of consumption are inputs. They find that worked hours are not significant, while consumption of sugar is noxious and consumptions of fish, vegetable, fruit and even tobacco-betel positively affect health. Household composition, household public good inputs and health environment are other significant determinants of illness. The effect of consumptions is directly considered rather than that of agricultural outputs. In our case, because of high auto-consumption rates for the food, this distinction may be less serious than it appears, and enables us to connect directly agricultural and HN processes.

[5] In that case, the shadow prices associated with the technology (see de Janvry, Fafchamps and Sadoulet (1991), Jacoby (1993) for discussions of the shadow price approach) are endogenous and depend on all inputs and outputs allocations, and on characteristics coming from preferences and constraints.

Behrman and Wolfe (1988) find in Nicaragua that women's schooling is a major determinant of women's health and nutrition, although they do not directly consider the cross-effects of women's health on nutrition status. Using data from Bangladesh, Pitt, Rosenzweig and Hassan (1990) find that the weight-for-height of household members is significantly determined by caloric intakes but also by the quality of water and especially age and sex characteristics. Murray, Feachem, Phillips and Willis (1992) argue that the relation between illness and decrease of activity is robust, as is the effect of income on illness rates.

Foster and Rosenzweig (1994) estimate a BMI (body mass index) production function (which is a nutrition production function) for adult peasants in the Philippines, in which the set of independent variables includes eight characteristics of the agricultural work, calories, an index for illness, lagged BMI and a dummy for male. Here, the influence of health on nutrition is considered although not the inverse impact of nutrition on health.

Despite all these studies, the general relationship between health and nutrition status and income is not well known (Strauss and Thomas 1995) and the direction of causality is not obvious. It seems that studies that have considered the relationship between incidence of diseases and level of income have found no or fairly small effects. Child height is generally positively affected by long-run resources but not substantially by short-run resources. On contrary, weight given height and BMI for children seem more responsive to current income but generally not to permanent income. For instance, BMI responds to predicted household expenditures in Ivory Coast.

Besides, the relationship between HN and different types of outputs for autarkic peasants is not known at all. However, von Braun and Kennedy (1986) present a survey of the effects of level and share of the aggregate cash crop in LDCs on household food consumption and nutrition, which shows mixed results. They are primarily interested in the impact of the commercialisation of the agricultural output. Finally, in a non-separable context, various agricultural inputs and endowments and household composition may also affect HN.

Strauss and Thomas (1995) show that many socio-economic characteristics of households affect their health and nutrition production functions. Parental education and family background positively affect the health of children. The quality of health services and of the sanitary environment seem as well to influence the health of household members, although migration and program placement bias make these effects difficult to interpret.

Finally, Strauss and Thomas mention that few effects of prices on illness in adults have been found in Indonesia. Other studies examining the influence of prices on health and nutrition show either non-significant effects (in Ivory Coast and the Philippines) or limited and dubious effects (India and Brazil). Our test rejects the introduction of prices (see section 4.1). All these elements suggest to exclude prices from HN equations and support the investigation of production functions rather than HN demand functions.

The aim of this paper is to estimate HN equations, which in contrast with other studies, incorporate the effects of past specific agricultural productions, in rural Rwanda. We investigate the most influential exogenous variables as well as the differences in separate crop outputs for their impact on nutritional and health status. We discuss in section 2 the theoretical model and the applied specification. In section 3, we present the data and the indicators. We test and estimate in section 4, a system of equations for health and nutrition status, with and without cluster-fixed effects, and weighted by the sampling scheme. We draw conclusions in section 5.

2. The theoretical and applied models

2.1. The theoretical model

We describe now a biological technology in a simple and aggregate structure so as to focus on the main features of our problem. We consider a single-person agricultural household which produces food outputs (Q_i,(I=1,...,5))[6] and non-food output (Q_6), from various inputs (in particular, the land used by the household, and the household labour force). The goods that are bought on the market are considered of marginal importance and the result of sold outputs through an 'indirect' technology involving transport and transaction costs. The household is characterised by a health indicator (H) and a nutritional indicator (N).[7] We do not consider the other agricultural inputs in the theoretical model as they do not pertain to the issue here. We rather focus on the variables at the household level that are related to our subject: Q_i (I=1,...,6), H and N.

On the one hand, good health (H) and good nutrition (N) enable a higher labour level and so increase output levels. On the other hand, non-toxic food consumptions generally improve nutritional status, whereas appropriate non-food consumption bought with the income of the sales of non-food production, such as health services, household equipment such as cooking and health material, and lodging, may improve health and nutritional status. Alcoholic beverages have a specific effect, often neglected in HN studies. They bring valuable nutrients, mainly calories, but in small quantities. They are also less vulnerable to contamination than water, but their impact on health and nutrition status can be very harmful because of their alcohol content. In particular, alcoholics cannot properly absorb folic acid, which leads to anaemia and mental sluggishness. One cannot rule out the possibility that specific food could sometimes be associated with diseases or intoxications, implying bad HN (see Salvato 1982, Lilienfeld and Stolley 1994, Tomkins 1994 for studies on such effects). Gupta et al. (1992) provide a detailed analysis of the effects of every specific type of food on nutritional status. However, the effects of consumption of products on HN are more or less hypothetical and must be investigated through an empirical analysis. Moreover, health and nutrition are mutually reinforcing (Tomkins 1994). Indeed, good health helps digestion and nutrient intake. In contrast, severe illness such as diarrhoea, other gastro-intestinal diseases and measles, or surgery, may result in proteino-energy malnutrition. On the other hand, good nutrition is necessary for good health and a deficient nutrition can be the origin of several diseases (gastro-intestinal diseases, or diseases related to vitamin and mineral deficiencies) and poisoning. Nutrient deficiencies also entail a general reduction in immunity and individuals suffering from protein-energy malnutrition are heavily colonised by intestinal parasites and bacteria.

6 We observe 6 agricultural outputs that will be described in section 2.2.

7 One sometimes finds a set of health and nutrition indicators in applied work. Generally, the health and nutrition of different household members are separated. To simplify, we only consider the global indicators at the household level. Furthermore, economic variables are generally observed at the household level (consumption, labour, production, etc.) and their attribution to individual members is problematic. For household behaviour models with individual allocations: Pitt, Rosenzweig and Hassan (1990), Chiappori (1992), Udry (1994).

All the considered interactions involve delays. Part of the labour input corresponding to observed agricultural outputs may have been supplied a long time before (for example for seeding or ploughing). Indeed, the harvest may occur several months and sometimes more than one year after the beginning of the agricultural work. Once the harvest is gathered, the product must be treated – e.g. beer bananas, which have to be crushed and mixed with water and honey, before being left for fermentation. The product is then stocked, sometimes for several weeks or months before its final consumption. If we now consider the possibility of a productivity fall due to illness, we must account for the fact that the illness could be anterior to the execution of the agricultural work. In that case, the health input in the agricultural technology corresponding to the final utilisation of the agricultural output belongs clearly to a past period.

On the other hand, it is well known that the biological production of HN from nutrient ingestion requires a substantial amount of time (Gupta et al. 1992 describe the ingestion and digestion processes). This is supported by the fact that short-run effects have often not been found to be significant in econometric studies (Deolalikar 1988). The effects of nutrients are cumulative and related to the HN history of individuals. Food consumption habits play an important role and the impact of better nutrition is necessarily progressive. Thus, the main effects of auto-consumptions (i.e. consumption from own-production) on HN may be spread over more than one year.

We dispose of indicators for agricultural outputs and HN for the agricultural year 1982–83. However, since we have calculated the agricultural output indicators from the value of their observed uses (auto-consumption, sales, gifts, etc), the corresponding outputs may have been cropped several months before.[8] In contrast, the health and nutritional indicators are specific to the period of the enumerator visit. The sequentiality involved in the definition of these indicators reduces the short-run feed-back effect of measured HN on observed agricultural output.

In a perfect market situation, the households can perfectly smooth their consumption, which is unrelated to agricultural shocks, but is related to permanent income. It is not the case in the quasi-autarkic context, and consumption is dependent on permanent and transient implicit income shocks and also on the transient and permanent composition of the agricultural output that determines directly most of consumption. The effects of agricultural shocks may not be conveyed through observed income. Moreover, several elements suggest that there is little stationarity in the interactions between HN and agricultural outputs. Firstly, the seasonal fluctuations in Rwanda are very erratic (Bezy 1996, Bulletin Climatique du Rwanda 1982, 1983, 1984). Secondly, fast demographic growth allied to land erosion modifies the agricultural context from one year to another. Thirdly, the economic development of the countryside and political conflicts make the economic situation evolve unpredictably. Finally, the effects of the different nutrients on HN, which are very imperfectly known by nutritionists and health sciences researchers, are certainly nevertheless very well perceived by poor and uneducated peasants. Because of these random or structural events, the fluctuations of the agricultural output are erratic, and the long term link between health, nutrition and production may be weak. The relations between HN and agricultural output may therefore be directed by short- run interactions. We translate this situation by assuming that peasants cannot plan precisely over several years and that long-run feed-back

[8] Information collected about the uses of agricultural production specific to the period of the enumerator's visit (at each quarter) and to the three preceding months (Ministère du Plan 1986). The harvest at the origin of these uses may have occurred during the preceding season.

effects are marginal. We expect that, due to the climatic fluctuations, the typical household cannot fully anticipate the levels of its future outputs, whatever its previously performed calculations (even including risk considerations).

The relations between agricultural and HN phenomena are described in the following framework. Let us denote Y_t the vector of usual agricultural outputs or inputs (netputs) in period t, and HN_t the vector of health and nutrition indicators in period t. We assume that the netput vector depends on HN (and other inputs which are omitted) through equation (1):

$$(1) \qquad f_t^1(Y_t\,; z) = g_t^1(H_{t-1}\,, N_{t-1}\,; z)$$

where f_t^1 is an implicit agricultural production function specific to period t, and g^1_t a function associated to the agricultural production scale of the household, such as explained by its lagged health and nutrition status (respectively H_{t-1} and N_{t-1}). Equation (1) accounts for delays involved in agricultural processes. z denotes a vector of exogenous variables explaining the heterogeneity of technologies. This formulation is similar to the agricultural production functions used in the literature, for which HN are inputs (Behrman and Deolalikar 1988, Strauss and Thomas 1995). We describe the biological process in system (2). It involves delays required for the biological synthesis and the fabrication of meals from the agricultural output.

$$(2) \qquad H_t = f_t^2(Y_{t-1}\,, N_t\,; z)$$

$$N_t = f_t^3(Y_{t-1}\,, H_t\,; z)$$

where f_t^2 and f_t^3 are two implicit biological production functions (respectively for the health process and for the nutrition process) associated with period t and representing interactions between HN and the levels of aggregate agricultural production that are inputs in the biological processes. One expects that the health process involves some influence of nutrition status, and that the nutrition process is dependent on health status. Under the assumptions set out above, it is possible to neglect the feedback effect of (1) on (2) and to treat the endogeneity of Y_t through instrumental variables methods. This type of approximation is of the same order as the hypotheses used for estimation of relationships of type (1) in the literature while neglecting the feed-back effects of agricultural production on health status considered as an input in the production function (Strauss 1986, Deolalikar 1988). The sequentiality involved in the studied indicators adds some credibility to this approach.

We solve by substitution the biological constraints (2) (assuming the non-nullity of the appropriate Jacobian) in two reduced equations for health and nutrition, so as to obtain the system of equations (3) which has interesting properties:[9]

- it is close to the structural system (2);
- the different agricultural outputs and inputs directly intervene in the explanation of HN;

[9] Note that system (3), corresponding to the estimated model, cannot be assimilated to a demand for HN conditional on agricultural output nor with a usual demand function with the income as a determinant, since in that case it would include prices (or shadow prices in case of missing markets). It is here a purely technological relationship.

- the role of exogenous variables is related to a given technological relationship.[10]

If the two processes had been considered as static and simultaneous with indicators corresponding to the date t (Y_t and HN_t), it would not have been possible to estimate equation (2) (describing the effect of production on HN) without also considering equation (1) (describing the feedback effect of HN on production), and vice versa. In that case, a simultaneous estimation of the equations associated with the economic productivity and the health indicators, as in Lee (1982), would be necessary. In contrast, since our framework is recursive, we can estimate equation (2) separately from equation (1), and the lagged output can be considered as exogenous.[11]

We attempt to reduce the impact of possible bias due to omission of past health and nutrition status by incorporating socio-demographic control variables in the equations.[12] However, several trials have shown that their inclusion does not strongly affect the estimates of the coefficients of the agricultural outputs.[13]

2.2. The applied specification

We specify the applied model from available indicators for agricultural inputs and outputs, as well as for health and nutrition. These indicators stem from cross-section data, excluding the specification of a dynamic model. We limit our model to relationships between observed variables. Furthermore, although we dispose of individual indicators for some characteristics of household members (demographic variables, anthropometric measures, symptom declarations), other characteristics have been recorded at the household level (agricultural inputs and outputs). Therefore, we estimate a model at the household level rather than at the individual level.

We specify two biological processes: the health process, mostly describing effects of illness, parasites and noxious environment; and the nutrition process, related to food ingestion. Each process is described by a Cobb–Douglas type production function because of the limited sample

[10] A model similar to the logic of that of de Janvry, Fafchamps and Sadoulet (1991) would consist in distinguishing the consumption and production of the same goods, to include a budget constraint in an optimisation program of the household utility and to specify the goods for which a market is not missing by identity between the appropriate shadow prices and observed prices. It will lead to demand functions (in particular HN demand functions) depending on observed prices and unobserved shadow prices. The unobserved shadow prices can be defined from the Kuhn-Tucker multipliers associated to the optimisation programme. They are solutions of the first-order Kuhn-Tucker equations and can be obtained as depending on levels of productions, consumptions and HN of the present and past periods. As we do not use consumptions indicators but only outputs indicators, this approach is not possible.

[11] Because of the duration of the process in which the agricultural output is transformed into consumed nutrients, and because of the calculus of the output indicators from their uses, we consider that our data at period t provides information about Y_{t-1} and HN_t, and enables us to estimate system (3).

[12] A more accurate specification of lags and durations is clearly not possible with our data. However, durations and lags of effects may be variable with the considered product or household. We assume that these variations do not seriously disturb the analysis.

[13] Alternatively, the estimated equations can also be considered as HN demands conditional on lagged output level (similarly to the approach of Pollak (1969)) and where price effects are not significant (see tests in section 4.1).

size so as to save on degrees of freedom.[14] We obtain:

$$(4)\ H = A \prod_i Q_i^{\beta_i} N^{\alpha}$$

$$(5)\ N = B \prod_i Q_i^{\delta_i} H^{\gamma}$$

where A, B, α, γ, β_i, δ_i are parameters.

Substitution and conversion into logarithms yields equations (6) and (7) in which we add, firstly, socio-demographic variables describing the difference of productivity of inputs and controlling for the main unobserved variables as we have suggested earlier, secondly cluster-fixed effects accounting for fixed unobserved local characteristics, and thirdly error terms accounting for unobserved heterogeneity and measurement errors.[15]

$$(6)\ \mathrm{Log}\ N_t = \sum_{i=1}^{6} b_{1i} \cdot \mathrm{Log}\ Q_{i,t-1} + X \cdot a_1 + \mu + v_1$$

$$(7)\ \mathrm{Log}\ H_t = \sum_{i=1}^{6} b_{2i} \cdot \mathrm{Log}\ Q_{i,t-1} + X \cdot a_2 + \lambda + v_2$$

where Q_i (I=1,...,5) are the values of food production for five food outputs, respectively beans (Q_1), other fruit and vegetables (Q_2), tubers (Q_3), other food output (Q_4) and traditional beers (Q_5). Note that banana for beers (in Q_5) and banana for food (in Q_2) are different varieties and come from different trees. Q_6 is the value of non-food production, in which we exclude firewood auto-production because it is mainly gathered by children, who are not considered in the average HN indicators (besides, its inclusion does not significantly change the results). X is the matrix of other exogenous characteristics, b_{1i}, b_{2i} (I = 1,..., 6) and a_1, a_2 are vectors of parameters, and $(v_1, v_2)'$ is the vector of error terms. μ and λ are cluster-fixed effects varying with the cluster g ($\mu_{ig} = \mu_g$ and $\lambda_{ig} = \lambda_g$ for all I in cluster g). The reduced effects of output variations on nutrition and health are composed of direct and indirect effects, since the basic health and nutrition processes involve cross-effects of health and nutrition. Because the structural model cannot be identified, the direct effects cannot be estimated.

14 By separating the equations for H and N, we implicitly assume non-jointness in input prices (see Kohli 1983) for the H and N processes, since only global productions and HN indices intervene as inputs in each process and not in terms of additive individual input allocations. The Cobb–Douglas specification implies separability between any input and output, and input and output homotheticity in both processes. Chambers (1988) discusses all these restrictions for multi-output technology.

15 Alternatively, independent variables and error terms can be considered as incorporated in parameters A and B in the structural technology.

3. Data and Indicators

3.1 The data

Rwanda is a small rural country in central Africa. Its population in 1983 was 5.7 million, nearly half of whom were under 15 years of age. Per capita GNP is around US $270 per annum. More than 95% of the population live in rural areas and agriculture accounts for 38% of GNP. The educational level of the population is low with half the adult population illiterate. In our application we study a peaceful situation corresponding to the agricultural year 1982–1983 (i.e. mostly 1983). Health status is very low, with a life expectancy of 44 years. The perinatal mortality rate is 86 (per 1000 births); the juvenile mortality rate is 222; the adult mortality rate is 395, and 34% of children under five years are too small for their age, indicating a prevalence of malnutrition.

3.5% of GNP is spent on health services (US $74 million), of which international aid finances 40%. Demographic growth is very high, with an average of 8.3 children per fertile woman, possibly the highest fertility rate in the world. This results in great pressure on land (the average farm covers around 1 ha), and food production per capita has fallen between 1980 and 1991 by 1.8% per year.[16] These few numbers illustrate the potential role of development policies directed to HN. The recent civil war dramatically increases the need for such policies. Besides, health and nutrition problems have been a major concern of public decision makers since the independence of the country (Colloque FOMETRO 1966, ONAPO 1985, Ministère du Plan 1985, 1988).

Data for the estimation is extracted from the Rwandan national budget-consumption survey, which was conducted by the government of Rwanda and the French Cooperation and Development Ministry in the rural part of the country (95% of the population according to the census of 1978, Bureau National du Recensement 1984) from November 1982 to December 1983 (Ministère du Plan 1986). 270 households were surveyed over a period of twelve months about their demographic characteristics, their budget, their food auto-consumption and their agricultural sales. We possess anthropometric measures and records of the number of forced rest days due to illness, for all household members over 14 years old. The value of household agricultural production is calculated from records of auto-consumption, agricultural sales and other uses of production.

The indicators benefit from intense preparation work. Indeed, every household was visited at least once a day (and often twice), during two weeks of every quarter. Every household had to register much repetitious information in a booklet during the absence of the enumerator. The set of surveyed topics was very broad and several aspects have been treated as redundant by different methods of collection. This enabled a better quality of the collection and we were able to supervise a thorough cleaning of the data that was carried out by more than thirty ex-enumerators after the collection. We were able to design sophisticated verification algorithms because of the many redundancies that are present in the data. Finally, we calculate the indicators with algorithms deliberately aiming at reducing the measurement errors from the combination of several

16 Source: *World Development Report 1991*, The World Bank, 1992.

information sources.[17]

3.2. The indicators

Table 1 show descriptive statistics for the main variables. We use only 157 observations in the estimation because of missing or invalid values. Health and nutritional indicators are based respectively on the number of forced rest days (due to illness) and BMI (body mass index), for all members between 18 and 50 years old inside the household. The health indicator H is defined as the inverse of the average number of forced rest days due to illness (plus one) per month, for adults over 18 and under 50 in the household. N is defined as the average ratio of weight to height squared (BMI), for adults over 18 and under 50 in the household.[18] That is, each individual ratio is calculated and we take the average of these ratios for all active adults. The average height of members is 1.35 metres (1.61 metres for active adults). The average weight of members is 38 kg (55 kg for active adults). The nutritional indicator (BMI) is 21.08 $kg.m^{-2}$ on average with very little dispersion (standard deviation of 2.04, first quartile of 19.7 and third quartile of 22.37). The number of forced rest days is 1.95 per month on average with a standard deviation of 3.1. Only 3.5% of households spent no days in forced rest, and we can therefore neglect the truncature bias in the estimation.

A set of exogenous variables is incorporated in the model. It includes, principally, land area, household composition, other socio-demographic characteristics and regional dummies.[19]

The land and the number of active members are the main inputs for the agricultural technology. They can be considered as deriving from the structural model but also as controls for heterogeneity of exploitations. Unfortunately, we do not have information about minor inputs nor about the quality of land and labour.

The number of children may substantially influence how the household deals with nutrition and health problems. First, scale economies may exist in cooking, food processing and health care. Second, households with many children may be more experienced in nutrition and health domains since the adults have had many opportunities to practise on their children. Third, children (and especially adolescents) participate in the HN process (for example by caring for their younger sisters or brothers, or preparing meals) but also in the agricultural processes which contribute to diminish the work load of the adults. In particular, children are generally partly or wholly

17 Indeed, when we compared the weekly recall information (one of the best collection methods for the data used in the literature) with the daily measures that we mostly used, we found a huge difference in the quality of information. For the main agricultural outputs, the weekly recall records show at least 30% of average underestimation.

18 We consider only adult members in calculating health and nutritional indicators. Mausner and Bahn (1985) recommend the use of different health indices for different stages of the life-cycle. Indeed, the growth curve and the type of disease are very sensitive to the age of children. Including children in the health and nutritional indicators would give too much importance to the household's sex and age structure and would cloud the relationships. For similar reasons, people over 50 years are not included in the health indicator since they may be chronically constrained to rest and their BMI is difficult to interpret (Tomkins 1994).

19 However, some of these variables are not significant in the estimations and we have excluded them to save on degrees of freedom. For instance, neither the place of birth nor the date of settlement of the head in the surveyed sector plays any role in the estimation, which suggests that the selectivity of the sample by migration, sometimes observed in health studies (Strauss and Thomas 1995), is not important in Rwanda. The religion is also non-significant.

responsible for fetching water and firewood. Fourth, young children are a burden for the family. They take up much of the time of female members, which may be diverted from the HN process for adults. Fifthly, they are more likely to be ill than other members and their presence increases the risk of contagion in the family. Sixth, household composition variables, as well as other socio-economic characteristics and dummies for regions, contribute to the control for unobserved variables and the reduction of the impact of possible missing lag-effects of HN from preceding periods.

The age and education of the head may partly explain experience and efficiency in the health and nutrition processes. In empirical studies, education has often been found to be positively correlated with better health and nutrition (Strauss and Thomas (1995) survey the effects of education variables).

Age and gender of members are potentially important determinants of HN, but their effects are likely to be very attenuated since we consider only average adult members in the household. Nonetheless, several variables account for differences in age and gender of members of different households. The average household size is 5.8 members with 1.02 children under three years old, 1.15 children over three and under 11 years old, and 3.49 active members (over 14 years of age). 2.1 adult members over 18 and under 50 years old were selected on average, as a basis for nutritional and health indicators. The average age of members is 20.7, the average age of household heads is 44.6 and their average number of education years is 2.1. Only 17.7% of household heads are women.

Households from the Tutsi minority ethnic group, in Rwanda of 1983, have often been excluded from political and public decisions. Therefore, Tutsi families may have a worse access to public centres that provide support in health and nutrition domains.

We focus particularly in this paper on the effects of agricultural outputs on HN. Beans bring a lot of calories and also many proteins, vitamins and minerals. Tubers (mostly sweet potatoes and cassava) are less nutritive although they have a notable nutritional role as the staple food. ‘Other fruit and vegetables’ are composed of different products, mostly banana and peas. ‘Other food’ includes, among other products, cereals, milk, meat and palma oil. It is a very heterogeneous good with generally high contents in proteins and fats. ‘Traditional beers’ are composed of sorghum beer and banana beer. Banana beer has a very high alcohol content. Sorghum beer contains more nutrients and is rare in the East region because the low altitude is unfavourable for the culture of sorghum. A dummy variable for the East crossed by the level of traditional beer output accounts for the highest prevalence of banana beer in the East. ‘Non-food’ is a heterogeneous good composed of coffee and tea and other industrial cultures but also of a variety of craft work.

The average agricultural exploitation area is 1.3 ha (13003 m^2) for an average food production value of 61 352 Frw (Rwandan Francs[20]). The larger food outputs in value are: traditional beers (18 893 Frw); tubers (13 362 Frw); and beans (10 134 Frw). Other fruit and vegetables (7 776

[20] In 1983, the average exchange rate was Frw 100.17 for US $1 (source: IMF, International Finance Statistics).

Frw), and non-food production (6 749 Frw) correspond to a smaller value of output.[21]

The auto-consumption rate, especially when remittances are included, is very high (66.4%). It is even higher for food consumption: 80.6% for beans, 94% for other fruit and vegetables; 89.4% for tubers; 62.2% for traditional beers; 43.5% for other foods. The importance of the consumption from own production is consistent with our decision to exclude the budget constraint from the modelling.

An examination of a few correlation coefficients and means by quintiles, weighted by the sampling scheme, provides a first picture of the interactions under study. The correlation coefficients of number of days of forced rest with per capita consumption or with nutritional status are not significantly different from zero. In contrast, the nutritional status is significantly positively correlated with per capita consumption ($\rho = 0.15$) and with the value of tubers output ($\rho = 0.23$). The nutrition status increases on average with the quintile of per capita consumption (from 20.7 in the first quintile to 21.9 in the last quintile), although the relations between number of days of forced rest and quintiles of per capita consumption is more irregular with a better health status in the centre of the distribution of per capita consumption (1.68 days in the third quintile) than for the poor (1.90 days in the first quintiles) or the rich (1.95 days in the fifth quintile).[22]

3.3. The Sampling Scheme

The sampling scheme (described in Roy 1983) has four sampling levels (communes, sectors, districts and clusters of households). The drawing of the communes has been stratified by prefectures, agro-climatic regions and altitude zones. One sector has been drawn in each drawn commune, and one cluster of three households have been drawn in each drawn district.

We calculate sampling weights that reflect the probabilities of drawings at every level from the modelling of the sampling plan and which can be used in Horwitz–Thompson estimators, for example Gouriéroux (1981) provides a discussion of the properties of these estimators. We calculate these weights so as to account for missing values (especially for anthropometric data) that oblige us to restrict further our sample and to eliminate households and sometimes communes. In that case, when the information of a sample unit cannot be used, we modify the drawing probability of the sample units of the same level, but only for that included in the same sample unit of the preceding level. This implies that different weights have to be used for the direct and the within-cluster estimations since only complete clusters are kept for the last case. The sampling weights partly correct for the attrition bias due to missing or aberrant variables and make the weighted sample representative of the whole population of rural households in Rwanda. Using sampling weights substantially improves the results of descriptive statistics and estimations.

[21] Market prices have been used to aggregate the quantities of the different varieties of these goods. The prices used are most of the time local (at the cluster level) and for the period of the consumption. Shadow prices accounting for market imperfections would probably be more appropriate for some households and some goods but they are not available. The market prices are then the best possible alternative. It must be understood that their use corresponds to a mere aggregation rule and not to a support of the perfect markets assumption.

[22] Note that the non-weighted statistics provide less expected results (with no increase of nutritional status with quintile of per capita consumption for example). To save space, all these basic statistics are not included in the tables, but are available on request.

Every cluster is associated with a set of unobservable but specific local characteristics, that are accounted for by incorporating fixed cluster-effects in estimations.

4. Estimation results

4.1 Tests

We obtain the estimates using OLS and 2SLS methods (weighted by the sample scheme) in which instrumental variables are: socio-demographic characteristics, household composition, prices.[23] We propose two different sets of estimates: 'Within-cluster' corresponding to the inclusion of cluster-fixed effects and 'Direct' without these fixed effects. Tables 2 and 3 show respectively the direct and within-cluster estimates of equations (6) and (7).[24]

Table 4 shows the t-statistics associated with each predicted endogenous variable in artificial regressions that we use to implement the Durbin–Wu–Hausman test for the exogeneity of agricultural outputs.[25] Because of the small sample size, OLS and 2SLS estimates are close and endogeneity problems seem moderate (although this may result from the low power of this test in finite samples). The main problems of endogeneity in direct estimates come from other food output in nutrition equation (t = 2.0), and in within-cluster estimates from the traditional beer output in health equation (t = -2.2). The endogeneity of the whole set of agricultural outputs is rejected in any set of estimates. This general exogeneity of the agricultural outputs supports the sequentiality of their effects on HN. However, to purge the results of each equation of the remaining endogeneity and because of the low power of the test, we favour in our comment the 2SLS estimates.

The GR^2 in the nutrition and health equations for the direct estimates, respectively 0.046 and 0.067, are small.[26] Moreover, the $\overline{GR^2}$ for these equations are much lower (respectively -0.013

[23] The geographical variability of prices (measured by the standard deviation across 5 regions) is half of the temporal variability (measured by the standard deviation across 4 quarters) which is large due to seasonal variations in aggregate agricultural output. Since we dispose of cluster prices, we may expect a good quality of these instruments. The price indicators have been collected in the closest market and are exogenous and should not be confused with shadow prices. We do not take a position about the complex mechanism through which they may influence the production composition and levels. Here, prices are merely used as instrumental variables and not associated with a bilinear budget constraint.

[24] Because of the low sample size, the 2SLS estimates are sensitive to the number and the explanatory power of the instrumental variables. Following Davidson and McKinnon (1993), we use an intermediate set of instruments to limit both the bias of the estimates and the proximity with inconsistent OLS estimates. Beyond the set of exogenous variables, the set of instruments includes: dummies for regions; matrimonial status and religion of the head; settlement year; place of birth of the head; masculinity ratio; household composition for age and sex classes; dummy for the head who can write; prices of beans, sweet potatoes, banana beer and soap powder, in the neighbourhood of the household. The predictive equations for the outputs can be obtained by request to the author.

[25] Indeed, the Student's test of the significance of the estimated coefficient associated to the predicted variable in the extended equation is equivalent to the Durbin–Wu–Hausman test (Davidson and McKinnon 1989).

[26] In 2SLS estimation, R^2 and adjusted R^2 are deficient measures of goodness-of-fit, and inappropriate criteria for model selection. In particular, it is possible to obtain negative R^2 and adjusted R^2 values. Pesaran and Smith (1994) provide a better measure, generalised R^2 (denoted GR^2), which is an asymptotically valid criterion of model selection. We extend this criterion by calculating an adjusted generalised R^2. The Pesaran-Smith GR^2 may be geometrically interpreted as the square of the cosine of the projection's angle of the dependent variables onto the subspace generated

and 0.0085).[27] Indeed, it is common in the health literature to obtain a weak goodness-of-fit from nutrition and health equations. One reason is the importance of missing explanatory factors in the data, including genetic factors. Furthermore, because of the complex dynamic processes involved, even calorie intakes are not always significant in cross-sections (Deolalikar 1988). The values of R^2 and GR^2 are much larger for the within estimates ($GR^2 = 0.30$ for the nutrition equation and $GR^2 = 0.41$ for the health equation).[28]

Table 5 shows the Fisher's statistics for the tests of identifying instrumental variables (IIV). The hypothesis of no effect of the IIV in the prediction of the possibly endogenous output variables is rejected for the traditional beer output in the East region in the case of direct estimates (with or without sampling correction). This hypothesis in the case of within estimates is rejected for fruit and vegetables, tubers, traditional beers, other food and non-food outputs, without sampling correction, and for all outputs when the sampling correction is implemented. The 2SLS estimates with sampling correction are therefore supported by the IIV test.

Table 6 shows the Fisher's statistics for different hypotheses corresponding to the nullity of sets of coefficients. Slightly different sample sizes stem from missing values for variables incorporated in some of the tests. Four hypotheses have been tested. H_0^1 is the nullity of the coefficients of all output variables. To accept this hypothesis would mean that the effects of agricultural outputs on HN are non-existent or too weak to be detected in our data. H_0^2 is the nullity of the coefficients of prices that have been added to the direct and within-cluster specifications. Only four prices are available for every cluster: those for beans, sweet potatoes, banana beer, and soap powder. To accept H_0^2 would mean that market prices have no or very weak effects on HN and would be an additional argument in favour of the autarkic model. H_0^3 is the nullity of the coefficients of the logarithm of per capita consumption that have been added to the direct and within-cluster specifications. To accept this hypothesis would mean that once the effects of socio-demographic

by the predictions of the independent variables.

27 In the classical linear regression model, we have $Y_i = X_i b + u_i$ where $E(u_i | X) = 0$ and $E(u_i^2 | X) = \delta^2$, $\forall I = 1$ to n, where Y_i is the value of the independent variable for observation I, X_i is the transposed vector of the explanatory variables for observation I and b is a vector of parameters. Applied across n observations, we obtain $Y = X\,b + u$. $\hat{b} = (X'X)^{-1} X' Y$ is the well-known OLS estimator. If W is the matrix of instrumental variables, $\tilde{b} = [X' W (W' W)^{-1} W' X]^{-1} X' W (W' W)^{-1} W' Y$ is the 2SLS estimator and the vector of residuals of the 2SLS estimation is $\tilde{u} = Y - X \tilde{b}$.

Note that $R^2 = 1 - \frac{\tilde{u}' \cdot \tilde{u}}{S}$ where $S = \sum_{i=1}^{n} (Y_i - \bar{Y})^2$ and $\bar{Y} = \frac{1}{n} \sum_{i=i}^{n} Y_i$. The vector of prediction errors from 2SLS is $\hat{u} = Y - W (W' W)^{-1} W' X \tilde{b}$ and $GR^2 = 1 - \frac{\hat{u}' \hat{u}}{S}$. The corrected indicators can be defined as $1 - \bar{R}^2 = \frac{n}{n-k} \cdot (1 - R^2)$ and $1 - \overline{GR^2} = \frac{n}{n-k} \cdot (1 - GR^2)$, where k is the number of explanatory variables.

28 Note that they cannot be directly compared with the corresponding statistics for the direct estimates since both samples and the variables are different. However, the within estimates correspond certainly to a much better adequation since for a random sample with the same number of degrees of freedom, the OLS direct estimate on a selected sample yields only $R^2 = 0.21$ and $\bar{R}^2 = -0.033$ for the nutrition equation and $R^2 = 0.31$ and $\bar{R}^2 = 0.098$ for the health equation.

characteristics and agricultural outputs have been taken into account, the living standards levels do not matter much for HN. This would support the absence of separation of the behaviour by a budget constraint in which the production effects would be summarised by a general income effect. In a sense, this can be considered as a weak test of the hypothesis of separability, similarly to Benjamin (1992). H_0^4 is the nullity of the coefficients of fixed cluster-effects. Only a restricted sample can be used for this test so as to consider only households belonging to complete clusters observed without missing variables.

H_0^1 is rejected for the within estimates (except for 2SLS of the health equation), and for the nutrition equation for the direct estimates. The global effects of outputs on HN are therefore more important for the nutrition equation than for the health equation. However, the coefficient of non-food output in direct estimates and the coefficient of fruit and vegetables in within estimates are significant in the health equation. Since the estimated equations are reduced-forms derived from two fundamental biological processes, it is necessary to keep the same independent variable in every equation. However, it is clear that the impact of the output structure is much more pervasive for the nutrition status than for the health status, for which only specific goods seem to matter.[29] H_0^2 is not rejected for any estimates. This supports the rejection of the perfect markets framework.

H_0^3 is rejected in two cases for the inconsistent OLS estimations, but never rejected for the consistent 2SLS estimates nor for the set of both equations with any estimation method. Thus, the living standard level does not seem to contribute to the explanation of HN, once the levels of the different agricultural outputs have been taken into account and corrected for their endogeneity. A separable model would have implied non-significant coefficients for agricultural outputs and a significant coefficient for the per capita consumption. The result of this test confirms our expectations about the non-separability of consumption and production decisions of agricultural households in Rwanda.

H_0^4 is not rejected for OLS estimates, but is always rejected for consistent 2SLS estimates for all sets of equations. This suggests, as did the GR^2 tests, that the within estimates correspond to the best specification once the correction for endogeneity is made. Note that the low sample size implies probably a low power for the test and that there exist good theoretical reasons to incorporate fixed effects in any case. Indeed, they account for unobserved local characteristics that could matter a lot for HN, such as health and nutritional services, healthiness of the environment (quality of water; temperature and rainfall; presence of anopheles mosquitoes which convey malaria vectors; presence of other parasites, etc).

4.2. Estimates

Even if we insist on the direct intuitive effects of variables, recall that we derived the reduced estimated system from a technological structural model and that the complete explanation of effects may involve interactions between HN indicators. When commenting the estimates and the simulations, we assume that the dominant causality is directly described by equations (6) and (7), so as to simplify their exposition. This interpretation choice will not change the sign of the considered effects, if the product of cross-effects between health and nutrition is less than 1,

[29] Of course, such result are conditional to the type of health and nutrition indicator observed.

which is likely since the opposite assumption would correspond to unrealistic substitution elasticities of H and N, and when the considered effects have the same sign in both equations (6) and (7).[30]

The biased OLS-direct estimates underestimate the significant tubers output effect on nutrition and overestimate the significant effect of the head's ethnic group on health. The traditional beers in the East region have an effect on nutrition that does not appear in 2SLS. In contrast, the significant effects in the 2SLS for other food output and non-food output in the nutrition equation and non-food output in the health equation are not significant with OLS-direct. The biased OLS-within estimates overestimate the significant effects of tubers, traditional beers outputs (in and out of the East region) on nutritional status, and of other fruit and vegetables output on health status. They underestimate the significant effect of beans output on nutrition. Moreover, the significant effect of other food output on nutrition obtained with 2SLS-within is not significant in OLS-within.

We comment now the 2SLS direct estimates. The coefficient of masculinity ratio and gender of the head are never significant (nor for within estimates) and these variables have been excluded. The coefficients of the land area, the number of children for the two categories of children, the age and the education of the head, the outputs of beans, other fruit and vegetables; traditional beers (in and out of the East region) are not significant. The number of active members has a negative impact on nutrition which is compensated by the positive effect of the number of adolescents and of the average age of members. Thus, the family composition seems to matter a lot for nutrition status. Households with a Tutsi head are more likely to have bad nutritional and health status, which confirms their relatively bad situation. Tubers and other food outputs positively affect nutrition, while non-food output is associated with worse nutrition but better health.

The picture obtained with the 2SLS-within estimates is substantially different which suggests a possible bias of the 2SLS-direct estimates. The coefficients of the number of active members, the number of adolescents and the non-food output are no longer significant in any equation. All other included variables show significant effects. The land area negatively affects nutrition and health status, perhaps due to a larger work load for households with large farms. The number of children between 4 and 10 years old is associated with a better nutrition of adults, while the number of children under 4 is associated with a worse health of adults.[31] The age of the head influences the nutrition status negatively and the health status positively, although the average age of members has an opposite effect. This suggests an influence of the life-cycle of the household on HN. As we

30 In preliminary papers (Muller 1996a, 1996b, we have separately estimated nutrition and health production functions with different sets of explanatory variables, but also without interaction between N and H, nor incorporation of fixed cluster-effect, nor corrections for the sampling scheme. These previous estimations have yielded far fewer significant parameters, but are interesting as a benchmark of what the standard production function approach can produce. In the present paper we take the analysis a step further.

31 Several interpretations external to the specified model can be proposed for these effects. Among them, the number of infants and children is partly endogenous since families in good health and nutritional status may be more likely to have babies and a lower infantile mortality. Families with bad HN may also have more children because of replacement or insurance considerations. However, the lack of appropriate instrumental variables and the small sample size do not enable us to correct for the possible endogeneity of household composition.

mentioned in section 3.2., the effects of composition variables are subject to ambiguous interpretations since they are associated with domestic, HN and agricultural technologies. This makes the empirical analysis still more useful since no a priori theoretical signs of these effects are available. The estimates show that no naive one-way explanation would fit the data. Similarly to the direct estimates, the Tutsi ethnic group of the head is associated with worse nutrition and health status. The education of the head has a similar effect, which is more surprising, although it may still be interpreted as a reduced heterogeneity effect of technologies.

Beans, tubers and other food outputs have a positive effect on nutrition. These effects are consistent with the nutritional importance of beans and tubers in Rwanda since they are considered as the food basis. The analysis of the effect of other food output, which is a very heterogeneous good, is more complex. However, its average nutritional quality is probably very high with valuable contents in proteins, lipids and vitamins.

In sharp contrast, the traditional beer output has a significant negative impact on nutritional status. Here, the noxious effect of banana wine and sorghum beer consumptions counterbalances their possible positive energetic effect, perhaps in part through the decline of health status.[32] The consumption of banana wine is much higher in the East. This may explain the more negative coefficient of traditional beer output in the East. The negative impact of alcohol is important for nutritional status, which shows that a study based only on calories or other nutrient intakes would be biased. In designing health and nutrition policies aimed at poor peasants, fighting alcoholism may be as crucial as bringing nutrients to households.

The equation describing the health status response has few significant coefficients corresponding to agricultural outputs. This may reflect the imperfect and partial nature of our health index. However, other fruit and vegetables output, mainly composed of peas and plantain bananas, has a positive effect on health status. This is consistent with the rich content in vitamins and mineral salts of this category of products (Gupta et al. 1992).

Note, finally, that the non-food output has no effect either on nutrition or on health. It is easy to understand that this type of product (coffee, craft work, etc), which is generally not consumed by the household but sold, may have little direct effect on HN. However, this confirms also that, since these products are mostly sold, the markets interactions are not as important for the explanation of HN as the direct effects of auto-consumption.

We have estimated direct and within-cluster specifications without the correction for the sampling scheme. These results are available on request to the author. The estimated coefficients are generally much less significant than and less consistent with what could reasonably be expected. On the contrary, a positive significant effect of beans on the health status disappears with the correction. Therefore, accounting for the sampling scheme (also noted by Deaton (1995)) is

[32] It has been suggested that the production of banana beer could be endogenous in the nutrition equation, since households producing a large banana surplus compared to their own consumption and unable to commercialise it could use it to make banana beer. This hypothesis is to be rejected because banana for food consumption and banana for beer are different varieties coming from different trees. The exogeneity of the banana beer output is based on our sequential framework and in case it would not be sufficient, we control for endogeneity by using instrumental variables estimation methods and control variables.

important, especially with a small sample size.

The estimation results suggest that a policy providing incentives to substitute crops used in beer production by crops containing missing nutrients may be beneficial to HN. In particular, the substitution for banana trees of tubers and bean cultures would produce positive effects.[33] The positive impact of banana beer output reduction is apparently even more important than the positive effect of increases in other agricultural outputs. The agronomical conditions required for this policy are satisfied because the land occupied by crops used in beer fabrication is generally of the highest available quality for the household, especially for banana trees.

This policy particularly appeals for Rwanda where the land is very scarce and the consumption of traditional beers is widespread. Moreover, alcoholism has been known for a long time to be a very serious problem among Rwandan peasants (Colloque FOMETRO 1966). Several strategies to reduce its prevalence have been discussed during the preparation of the Plan of Rwanda in which we were involved (Ministère du Plan 1985, 1988). Unfortunately, their implementation is generally difficult. For example, the taxation of banana beer would attract strong political opposition from peasants who are very attached to the consumption of traditional beers, in part because it plays a major social and ceremonial role. Furthermore, banana trees contribute to the feeding of animals, and provide green fertilisers, straw and even fire material. Thus, Bezy (1990) consider that banana tree culture is the main obstacle to change in Rwanda.

However, more radical policies seem now possible because, firstly, following the dramatic ethnic troubles of 1994, development agencies and the public authorities are aware of the consequences of widespread poverty. Changes in composition of the agricultural output can be obtained by settling a more efficient system of markets, in order to decentralise welfare objectives through agricultural prices policy. However, taxation or other price disincentives may fail because of limited administrative infrastructure and imperfections of markets. This could also be the case for the direct control of cultivated areas. However, the obligation of cultivation of tea or coffee for many peasants in Rwanda is an example of a centrally planned constraint on the composition of the agricultural output. This policy has been implemented with relative success, although the situation was not favourable since peasants consider generally that the return to industrial crops is much inferior to food crops. It may also work for imposed limitations of the culture of banana trees directed to the fabrication of beer.[34]

[33] If we consider only the estimation results, that do not incorporate various side-effects attached to the behaviour or the situation of peasants.

[34] Thus, the feasibility of the policy does not seem out of reach. We do not take a position on the means necessary to implement such a policy, which is another (important) debate, in which more complex interactions in a macroeconomic framework should be considered.

5. Conclusion

Because of the proximity to subsistence of peasants in developing countries, health, nutrition and agricultural technologies may be closely connected. This is the origin of vicious circles impeding the development of human resources in these countries.

Because of the presence of market imperfections and non-separation of consumer and producer decisions, the composition of the agricultural production may have a direct effect on health and nutrition status. However, no estimations of the impact of specific agricultural outputs on health and nutrition status are present in the literature. Because of the presence of lags in agricultural and biological processes, and in observed indicators, we specify a sequential model where health and nutrition status depend on productions of a preceding period.

We estimate equations for peasants in Rwanda, in which nutrition and health levels are related to the main agricultural outputs and to socio-demographic characteristics. We incorporate cluster-fixed effects and account for the sampling scheme. The model is supported by several statistical tests. Beans, sweet potatoes and a heterogeneous food output are found to have positive impacts on nutrition status while traditional beers have a very noxious effect. Other fruit and vegetables output are associated with better health status. This suggests a health and nutrition policy based on the substitution for the culture of banana beer trees of other agricultural products, such as beans or tubers.

Because the data comes from a cross-section, we can only investigate short-term effects and these estimates must be considered as a first step towards the resolution of a difficult question. It is possible that long-term effects would be smaller since households may adapt to an unfavourable environment (for example by changing the organisation of production). Moreover, the improvement or the degradation of human resources may entail changes in level and composition of agricultural output through its impact on the agricultural technology. In contrast, demographic growth, land erosion and political conflicts make the adaptation more and more difficult since they increase the pressure of constraints for peasants. Consideration of other side-effects and a macroeconomic framework would be necessary for a more thorough analysis of policies.

More evidence, particularly from a larger sample or with dynamic effects estimated from panel data, is yet to be established. The whole set of interactions between agriculture, health and nutritional phenomena remains to be estimated as well as a structural model introducing the role of prices through specified imperfect institutions of commercialisation. Furthermore, the aggregate framework that we propose could be extended by including intra-household allocations between members and consideration of individual health and nutrition status.

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Tables

Table 1: Descriptive statistics for the main variables
(corrected by sampling scheme)

Variable	Average (with weight)	Average (without weights)	Standard deviation
Nutritional indicator (N) (kg.m^{-2})	21.072	20.974	2.03733
Minus Health Indicator (- H) (days per month)	1.94557	2.3257	3.128
Bean output (Frw)	10133.7	9968.97	7375.2
Other fruit and vegetables output (Frw)	7775.99	8504.65	10596.2
Tubers output (Frw)	13361.93	12873.82	9998.3
Traditional beer output (Frw)	18893.08	20032.82	18046.5
Other food output (Frw)	6359.03	6922.21	12704.1
Non-food output (Y) (Frw)	749.13	707.8	1524.95
Land area (m^2)	13003.24	12876.59	14206.9
Number of infants (under 4 years of age)	1.02137	1.0127	0.824
Number of children (over 3 and 11 years of age)	1.15141	1.1975	1.0886
Number of adolescents	0.78524	0.8217	0.9773
Proportion of selected members	0.37126	0.375	0.1674
Household size	5.75811	5.7389	2.1696
Number of active members	3.49342	3.529	1.651
Average age of members	20.70124	20.4561	7.959
Age of the household head	44.615	44.1788	14.371
Years of education of the household head	2.11	2.0382	2.3963
Dummy for female household head	0.17733	0.1656	0.3729
Dummy for Tutsi household head	0.15295	0.1465	0.3547
Masculinity Ratio	1.30551	1.2818	0.9812
Dummy for North-West Region	0.152	0.1338	0.341
Dummy for East Region	0.2808196	0.242	0.4297
Average height of members (cm)	136.439	136.281	15.649
Average height of selected members (cm)	161.823	162.086	6.7841
Average weight of members (kg)	37.9981	37.798	7.9021
Average weight of selected members (kg)	55.0317	54.984	6.0617
Total production	61351.87	60295.8	30248.2
Total consumption	56529.24	56795.3	20865.8
Subsistence ratio	0.658029	0.6559	0.1516
Food subsistence ratio	0.7470196	0.7413	0.1511

157 observations. Frw is Rwandan Francs.

Table 2: Estimation results

(Direct corrected by sampling scheme)

	Nutritional status		Minus health status	
Estimation method	OLS	2SLS	OLS	2SLS
Independent variables:				
Constant	-6.314095** (-39.93)	-6.414777** (-30.55)	0.743138 (0.52)	0.839865 (0.45)
Logarithm of number of active members	-0.077138** (-2.19)	-0.090800** (-2.41)	0.357570 (1.13)	0.468419 (1.39)
Logarithm of land area (m^2)	-0.00243567 (-0.23)	-0.00673636 (-0.61)	-0.034044 (-0.36)	-0.028268 (-0.29)
Number of infants	0.00763697 (0.61)	0.00858446 (0.65)	0.186526** (1.64)	0.167653 (1.43)
Number of children	-0.00390214 (-0.43)	-0.00474312 (-0.49)	0. 077112 (0.94)	0.071517 (0.83)
Number of adolescents	0.037918** (2.52)	0.042449** (2.63)	-0.040077 (-0.29)	-0.086649 (-0.60)
Age of head	-0.00086981 (-0.80)	-0.00096686 (-0.84)	-0.015415 (-1.57)	-0.015997 (-1.55)
Average age of members	0.00367914* (0.0020939)	0.00427352** (1.96)	0.018720 (0.99)	0.016791 (0.86)
Dummy for Tutsi head	-0.047829** (-2.30)	-0.053058** (-2.45)	0.398360** (2.13)	0.378791** (1.96)
Education of head	-0.00405688 (-1.11)	-0.00450510 (-1.15)	-0.036676 (-1.11)	-0.035480 (-1.02)
Bean output (Frw)	-0.00273693 (-0.41)	0.00076348 (0.07)	-0.025252 (-0.42)	-0.114205 (-1.19)
Other fruit and vegetables output (Frw)	-0.00931697 (-1.40)	-0.00921259 (-0.99)	0.015934 (0.26)	0.045766 (0.55)
Tubers output (Frw)	0.026326** (2.63)	0.032161** (2.01)	-0.036427 (-0.40)	0.029829 (0.21)
Traditional beer output (Frw)	0.00331933 (0.44)	0.00690148 (0.68)	0.036898 (0.55)	0.018504 (0.19)
(Traditional beer output) x (Dummy for East)	0.00359184* (1.66)	0.00332457 (1.35)	0.024285 (1.24)	0.030739 (1.40)
Other food output (Frw)	0.00375373 (1.42)	0.00926555** (2.49)	0.00697847 (0.29)	0.00886858 (0.27)
Non-food output (Frw)	-0.00122007 (-0.55)	-0.0052273* (-1.67)	-0.031471 (-1.57)	-0.060345** (-2.16)
R^2	0.1865	-	0.1099	-
$\bar{R}^2$	0.0922	-	0.0067	-
GR^2	-	0.046	-	0.0665
$\overline{GR}^2$	-	-0.0133	-	0.0085

Student's t in parentheses. 157 observations. * = Significant at 10% level. ** = Significant at 5% level.

Table 3: Estimation results

(Within-cluster corrected by sampling scheme)

	Nutritional status		Minus health status	
Estimation method	OLS	2SLS	OLS	2SLS
Independent variables:				
Logarithm of number of active members	-0.057188 (-1.45)	-0.053131 (-1.28)	0.328072 (0.90)	0.303223 (0.79)
Logarithm of land area (m^2)	-0.029453* (-1.92)	-0.034076** (-2.11)	0.230280* (1.61)	0.254704* (1.71)
Number of infants	0.015681 (1.03)	0.012150 (0.78)	0.230392* (1.63)	0.239658* (1.66)
Number of children	0.033776** (2.97)	0.032716** (2.67)	0.038513 (0.36)	0.034716 (0.31)
Number of adolescents	0.026879 (1.58)	0.021351 (1.19)	0.087991 (0.55)	0.109096 (0.66)
Age of head	-0.00318871** (-2.22)	-0.00326267** (-2.19)	-0.049412** (-3.70)	-0.048664** (-3.54)
Average age of members	0.00727827** (2.78)	0.00694864** (2.57)	0.052405** (2.15)	0.052602** (2.11)
Dummy for Tutsi head	-0.051377* (-1.60)	-0.060349* (-1.82)	0.997275** (3.33)	1.040777** (3.41)
Education of head	-0.012941** (-2.47)	-0.012694** (-2.22)	0.089102* (1.82)	0.094269* (1.79)
Bean output (Frw)	0.022977** (2.53)	0.027703** (2.66)	-0.055341 (-0.66)	-0.100788 (-1.05)
Other fruit and vegetables output (Frw)	-0.00852321 (-0.88)	-0.00958829 (-0.89)	-0.221531** (-2.45)	-0.270051** (-2.73)
Tubers output (Frw)	0.060826** (2.90)	0.059537** (2.55)	0.240211 (1.23)	0.238500 (1.11)
Traditional beer output (Frw)	-0.025020** (-2.46)	-0.027586** (-2.42)	0.037074 (0.39)	0.079030 (0.75)
(Traditional beer output) x (Dummy for East)	-0.079387** (-2.94)	-0.085244** (-2.60)	0.260007 (1.03)	0.246951 (0.82)
Other food output (Frw)	0.00538351 (1.33)	0.012080** (2.21)	-0.015988 (-0.42)	-0.040140 (-0.80)
Non-food output (Frw)	0.00385433 (1.38)	0.00216933 (0.68)	-0.018194 (-0.70)	-0.00994023 (-0.34)
R^2	0.3383	-	0.4189	-
$\bar{R}^2$	0.2327	-	0.3261	-
GR^2	-	0.301	-	0.405
$\overline{GR}^2$	-	0.180	-	0.303

Student's t in parentheses. 111 observations. * = Significant at 10% level. ** = Significant at 5% level.

Table 4: t and F Statistics for the Durbin–Wu–Hausman Test

(Direct estimates weighted by sampling scheme)

Variable	Nutrition	Health
Logarithm of traditional beer output) x (dummy for East region)	0.576	-1.377
Logarithm of bean output	0.624	-1.370
Logarithm of other fruit and vegetables output	-0.036	0.404
Logarithm of tubers output	0.803	0.411
Logarithm of traditional beer output	0.905	-0.796
Logarithm of other food output	2.025	-0.085
Logarithm of non-food output	-1.368	-1.424
F statistic for the set of every agricultural outputs	-2.87	2.72

$F_{1-\alpha}(7,131) = 1.763$ for α=10%, $F_{1-\alpha}(7,131) = 2.080$ for α=5%, $F_{1-\alpha}(7,131) = 2.779$ for α=1%,

(Within-cluster estimates weighted by sampling scheme)

Variable	Nutrition	Health
Logarithm of traditional beer output) x (dummy for East region)	-0.416	-0.426
Logarithm of bean output	-1.350	-1.510
Logarithm of other fruit and vegetables output	-0.136	-0.825
Logarithm of tubers output	-0.968	-0.342
Logarithm of traditional beer output	-1.438	-2.185
Logarithm of other food output	1.373	-1.044
Logarithm of non-food output	-0.677	-0.460
F statistic for the set of every agricultural outputs	0.830	0.697

$F_{1-\alpha}(7,86) = 1.788$ for α=10%, $F_{1-\alpha}(7,86) = 2.118$ for α=5%, $F_{1-\alpha}(7,86) = 2.854$ for α=1%.

Table 5: F Statistics for the tests of identifying instrumental variables
(weighted by sampling scheme)

Variable	Direct estimates	Within estimates
(Logarithm of traditional beer output) x (dummy for East region)	2.31	1.83
Logarithm of bean output	1.007	1.59
Logarithm of other fruit and vegetables output	1.416	2.16
Logarithm of tubers output	1.10	1.99
Logarithm of traditional beer output	1.23	2.06
Logarithm of other food output	1.26	1.67
Logarithm of non-food output	1.30	2.36

$F_{1-\alpha}(63,147) = 1.301$ for α=10%, $F_{1-\alpha}(63,147) = 1.402$ for α=5%, $F_{1-\alpha}(63,147) = 1.611$ for α=1%,
$F_{1-\alpha}(32,102) = 1.411$ for α=10%, $F_{1-\alpha}(32,102) = 1.557$ for α=5%, $F_{1-\alpha}(32,102) = 1.866$ for α=1%.

Table 6: F Statistics for various tests

(Direct estimates)

Tests	Estimates	OLS	OLS	2SLS	2SLS
		N	H	N	H
Outputs	Direct	2.049 (7,143)(R)	0.740 (7,143) A	2.401 (7,143) R	1.161 (7,143) A
Outputs	Within	3.10 (7,101) R	2.24 (7,101) R	1.829 (7,101) (R)	1.4948 (7,101) A
Prices	Direct	0.613 (4,138) A	0.0739 (4,138) A	0.4841 (4,138) A	0.3797 (4,138) A
Prices	Direct both	0.55286	(8,310) A	0.3809	(8,276) A
Log per capita consumption	Within	t = 1.80 (R)	t = 1.33 A	F = 1.353 (1,94) A	F = 0.2361 (1,94) A
Log per capita consumption	Direct	t = 1.28 A	t = 2.48 R	F = 1.783 (1,94) A	F = 0.4142 (1,94) A
Log per capita consumption	Within both	1.783	(2,188) A	0.2491	(2,188) A
Log per capita consumption	Direct both	5.883	(2,276) A	0.4142	(2,276) A
Fixed effects	Each	0.867 (34,94) A	0.552 (34,94) A	1.880 (34,94) R	1.5126 (34,94) R
Fixed effects	Both	0.557	(68,188) A	1.5176	(66,188) (R)

The tests compare estimates with and without tested variables. The first number shown in each cell is the value of the test statistics, then come the two parameters of the Fisher distribution under the null hypothesis and finally the result of the test (R = rejection of the null hypothesis at 5% level; (R) = rejection of the null hypothesis at 10% level; A = non-rejection of the null hypothesis at 10% level). The formula of the F statistic for 2SLS is different from the usual one used for OLS. Indeed, some sums of squared errors intervening in the formula are calculated from prediction errors rather than from 2SLS residuals. The null hypothesis is the nullity of the coefficient of the appropriate independent variables.