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ANALYSIS

Do international commodity prices drive natural resource booms? An empirical analysis of small-scale gold mining in Suriname

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Abstract

Natural resource booms have been central to conservation and development in resource-rich Latin American countries, yet the origin of these events remains poorly understood. Understanding the socioeconomic drivers of resource booms is important because such sudden increases in natural resources extraction are usually ecologically and economically unsustainable. This paper analyzes the socioeconomic drivers of small-scale gold mining, which is degrading ecological resources and the health of people in the Amazon region. Two conventional hypotheses are tested: (1) International prices of gold drive the Amazon gold rush, and (2) National economic recession encourages small-scale gold mining. A simple empirical model is presented to link the gold mining histories of local miners to international and national trends. The analysis indicates that theories that explain corporately-driven resource extraction may not apply to the behavior of small-scale producers. It appears that extractive booms that are driven by local resource users can occur independently of global price markets. The Suriname case further suggests that inhibited national economic development can be the cause of a natural resource boom, and not only a consequence as some researchers propose. The author concludes that conservation policies for Suriname should act to stabilize the national economy and to promote more sustainable mining methods. © 2001 Elsevier Science B.V. All rights reserved.

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1. Introduction

This paper analyzes the relative impact of international commodity prices and national economic trends on the current gold mining boom in Suriname, South America. The interlinked economy

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and ecology of resource-rich Latin American countries have historically been shaped by boom and bust cycles in the extraction of rubber, oil, diamonds, and minerals including gold (Barham et al., 1998; Sachs and Warner, 1999). Such sudden increases in the extraction of natural resource deserve attention because they often produce social disruption, economic volatility, and ecological degradation (Cleary, 1990; Schmink and Wood, 1992; MacMillan, 1995; Barham and Coomes, 1996). These episodic events are seldom sustainable in either an economic or an ecological sense as they involve non-renewable resources, environmentally destructive extraction techniques, and a limited tendency to reinvest revenues in secondary sectors. Why natural resource booms occur when and where they do, however, remains poorly understood.

Conventional theory proposes that natural resources booms are triggered by changes in global commodity prices, and collapse when those prices fall (Cleary, 1990; Mainardi, 1995; Barham and Coomes, 1996). In the case of gold mining, for example, gold production trends are believed to track changes in the international price of gold (Selvanathan and Selvanathan, 1999). The price-production link is intuitive; a rise in the price of a commodity increases the value of deposits, providing an incentive to intensify exploration and exploitation efforts.

In this paper, I argue that natural resource booms can occur independently of global markets. Relative unresponsiveness to commodity prices can be expected when small-scale resource users rather than multinational corporations produce the boom. Support for my argument comes from the Suriname Amazon. Here, gold production has increased from <2 kg per year in 1976 (Bubberman, 1977), to 30 kg per year in 1985 (Gemerts, 1986), to an estimated 15 000 kg per year in 1997 (Veiga, 1997). Small-scale miners extract virtually all this gold.

The Suriname gold rush is not an isolated case, but rather reflects a worldwide upsurge in informal mining activity (Barry, 1996; UN, 1996). In the past three decades, numerous low-income countries have welcomed small-scale gold mining because it employs their poorest populations and provides revenues for governments who can control the activity. In the Brazilian Amazon alone, more than 4 million people may derive their livelihoods from small-scale mining and the surrounding service economy (Sponsel, 1997). Global observers, on the other hand, fear the impacts of mining on people and ecosystems; small-scale gold mining causes mercury pollution, facilitates the transmission of malaria and sexually transmitted diseases, removes forest cover, disturbs wildlife populations, and increases sediment loads in creeks and rivers. These effects have been documented for Suriname (Healy, 1996; De Kom et al., 1998; Peterson and Heemskerk, 2001) and elsewhere in the Amazon (Cleary, 1990; Akagi et al., 1995; Veiga et al., 1995; Bezerra et al., 1996; MacMillan, 1996; Faas et al., 1999). Appendix A describes the ecological effects of mining in Suriname in greater detail.

Reducing or preventing the ecological impacts of mining requires models that explain and predict the eruption of gold rushes. I propose a model that links temporal changes in the local number of gold miners to international and national time series. Social scientists have been urged to recognize interactions across spatial and temporal scales, and to improve the methods for studying them (Gibson et al., 2000). This analysis addresses that challenge by integrating micro and macro level data in one model. This model allows me to test two popular hypotheses about the Amazon gold rush:

1. High gold prices drive the Amazon gold rush.
2. National economic recession encourages small-scale gold mining.

Descriptive work has supported both hypotheses (Cleary, 1990; Schmink and Wood, 1992; MacMillan, 1995). However, the quasi-legal nature and poor documentation of small-scale extractive activities have been barriers to testing the hypotheses empirically. Suriname presents an intriguing case to test the model because its mining boom broke out several years later than in Brazil, which has informed many existing gold rush theories. This study challenges these theories by suggesting that international commodity prices can be relatively unimportant in the development of extractive booms.

2. Area description

2.1. Background

Suriname is located on the South American continent, North of Brazil between Guyana and French Guiana. The country is small in size with a total land area of 163 820 km^2 (ABS, 2000). The small Suriname population of 425 000 (ABS, 2000) lives almost entirely in and near the capital city of Paramaribo. Only Amerindians (est. 10 000 people) and Maroons (est. 50 000 people), descendants of escaped African slaves, live in the tropical rainforest that covers more than 80% of Suriname (Kambel and MacKay, 1999). These forest peoples gather wild fruits and nuts, hunt and fish, practice small-scale agriculture and mining, and use forest products to construct houses, boats, and other household items. Despite traditional subsistence activities, however, the largest share of Suriname's rainforest shows few signs of anthropogenic disturbance and remains dominated by indigenous vegetation (Mittermeier et al., 1990). Between 1980 and 1995, the average annual deforestation rate was $< 1\%$ (WRI, 2000).

Since the early 1980s, Suriname's forest has been explored by thousands of small-scale gold miners. I use the term small-scale gold miners to refer to informal, manual or mechanized miners who use rudimentary processes to extract gold from secondary and primary ore bodies. Today, most small-scale gold miners work in teams that use hydraulic methods. Mining teams usually consist of a machine owner, 5–6 workers, an overseer, a cook, and occasionally carpenters, carriers and other temporary laborers. The machine owner is responsible for all equipment, fuel, lodging, food, and other daily expenses. In return for his or her investment, the machine owner receives 70% of all gold extracted. The remaining 30% is divided among the pit workers. The cook and others usually receive fixed wages that are paid in gold by either the machine owner or the pit workers.

Mining experts have estimated that between 10 000 and 20 000 small-scale gold miners are working in Suriname (Heemskerk, 2001). This study focuses exclusively on Maroons, who constitute about a quarter of the mining population. It is believed that the remaining three-quarters of miners are Brazilian migrants (Veiga, 1997). A chronic shortage of human and material resources has prevented the Suriname forest service from either regulating mining or excluding gold miners from protected areas.

2.2. Research site

Fieldwork was conducted along the upper-Tapanahony River among the members of a Maroon group called the Ndjuka (Fig. 1). Most mining in the research region took place around the Sella Creek, a tributary of the Tapanahony

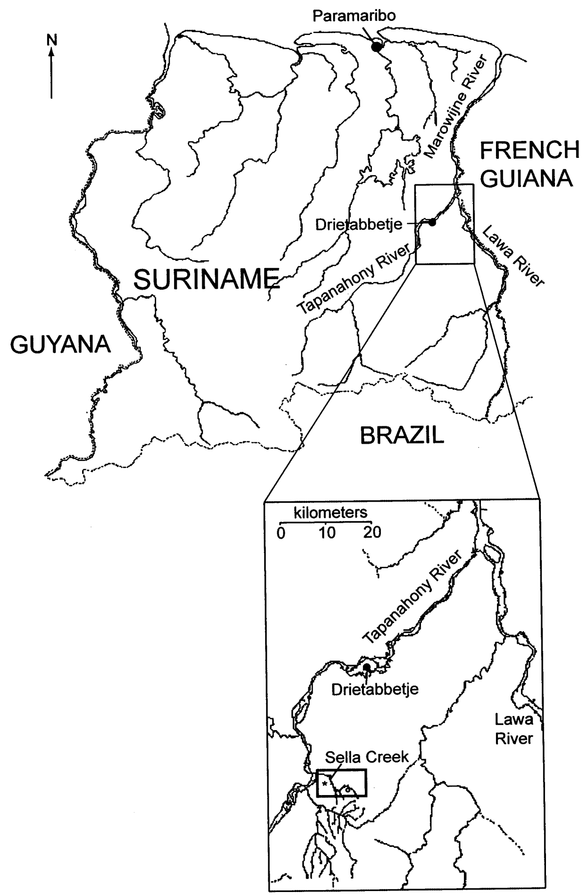

Fig. 1. Research site: Suriname, the Tapanahony region, and the Sella Creek mining area. The asterisk (*) presents the location of the base mining camp during the fieldwork.

River. All of the ≈60–70 gold mining camps in the Sella Creek mining area were owned by Maroons (Peterson and Heemskerk, 2001).

I observed much variation in the efficiency and profits of local gold mining operations. The monthly gold production of mining teams that revealed their earnings ranged between 275 and 2750 g, averaging 1129 g in the month prior to the interview ($N = 10$, $SD = 794$). Pit workers I interviewed reported gold earnings that ranged from 13 to 150 g per month, averaging 43 g per month. With the contemporary price of gold varying between eight and nine US dollars per gram, the average miner earned the equivalent of about US $350 ($N = 32$, $SD = 27$). In comparison, retired miners remembered that they used to recover about 10 g of gold per month when they panned gold in the 1950s and 1960s. My observations elsewhere in Suriname suggest that recovery rates are likely to increase as heavier equipment enters the area.

It should be noted that production costs have increased even faster. In 1998–1999, the price of the most frequently used 6-inch. mining machine was approximately US $20 000. This price included all technical appliances and 5 kg of mercury. Machine owners in the study area spent on average 600 g of gold per month to maintain their operations ($N = 21$, $SD = 421$). Because machine owners are responsible for all expenses, high production costs may not influence the decisions of laborers.

3. Methods

3.1. Using local data to estimate the number of gold miners over time

Field research took place between August 1998 and June 1999. A survey interview was conducted with 219 Ndjuka individuals. Of these people, 156 where either miners at the time of the interview ($N = 102$) or had been gold miners previously ($N = 54$). Their mining experience ranged from 1 month to 46 years, and averaged 7.6 years. All survey respondents were at least 16 years of age and averaged 34.5 years of age.

Each person with mining experience was asked what year he or she had entered mining and, if applicable, when he or she had exited. The analysis was limited to the period after 1970 because of concerns about the ability of people to accurately recall earlier dates. Of the 156 respondents with mining experience, 146 individuals provided detailed information about the years that they mined. The reported years of mining entry and exit of this group ($N = 146$) were used to calculate the number of active miners in the sample in each year between 1970 and 1998.

Age-distribution data were used to correct the annual number of active miners for attrition due to mortality and migration. Because there are no census data for the Ndjuka, I use the age distribution in my survey sample ($N = 219$). I had to make several assumptions. First, I assumed that my sample accurately represented the age distribution in the Ndjuka population. Second, I assumed that the population size has not changed since the 1970s. This assumption is probably accurate because Suriname population estimates for the interior have remained relatively constant over the past 30 years, as natural population increase has been countered by migration. By surveying urban as well as rural Ndjuka I captured migration to the city but not migration abroad. Third, I assumed that miners did not leave or die in numbers different from non-miners. This assumption is reasonable because only in the most recent years have violence and industrialization caused disproportionate health problems and mortality among gold miners.

Next I calculated how many people in the sample population were old enough to be gold miners in any given year between 1970 and 1998. Given that gold miners are usually at least 15 years of age, I calculated how many people in the sample were at least 15 in any given year t. To correct for attrition, the observed number of miners in year t was divided by the number of people who could have been miners in that same year (n), and multiplied by 100%. Thus, the percentage of active miners in the population in any given year t (Miners_t) was estimated as:

$$\text{Miners}_t = [(\text{Miners}_{t-1} + E_t - X_t)/n] \times 100\%,$$

where $Miners_{t-1}$, the number of active miners in the year prior to t, E_t, the number of new miners in year t, X_t, the number of people who left gold mining in year t, n, number of people in the sample population who were at least 15 years of age in year t.

3.2. Model specification

To reiterate, the model estimates the marginal effect of international and national indicators on the intensity of small-scale mining. The dependent variable is the estimated percentage of active gold miners in the local Ndjuka population ($Miners_t$). This variable is probably imprecise due to the absence of reliable national estimates on the mining population. Nevertheless, the measure does represent the general upward trend in Suriname small-scale gold mining reported in the national media (Ramcharan, 1996; Van der Kooye, 1997) and international reports (Healy, 1996; Veiga, 1997). I include the dependent variable at its natural log value to capture this upward trend rather than the absolute numbers of gold miners. Memory errors and smaller sample sizes create larger error terms in the early values for the dependent variable than in estimates for later years. I used a weighted least squares (WLS) model, with the trend variable year as the weighting factor, to reduce the effects of heteroskedasticity.

The model is based on the theory that people who make a job choice compare gold mining with other jobs, and choose the activity with the highest expected income. The explanatory variables are indicators of the potential incomes from gold mining and indicators of the potential incomes from other jobs. Job options outside the mining sector depend on unemployment rates, consumer prices, and the per capita gross domestic product (GDP). High unemployment indicates a low demand for labor, which complicates finding formal employment and may lower formal wages. High consumer prices decrease the purchasing power of wages, and a slowly growing or decreasing GDP per capita shows a lack of economic opportunities. These three variables measure national economic performance, thus allowing me to test the second hypothesis.

Gold mining incomes depend on the price of gold, the price of oil, and technology. The price of oil is relevant because mine operators use gasoline for transport, the operation of mining machines, and generators that deliver power for televisions and refrigerators. From field interviews, I estimated that fuel costs comprised more than half of the monthly variable expenses of mine operators. I expect that a rising price of gold (higher profits) and a decreasing price of oil (lower costs) encourage gold mining.

Increased profits due to improved mining technology may have attracted novices to mining. Unfortunately, it was not possible to quantify technological change. An appropriate proxy would be the migration of Brazilian miners who modernized Suriname's small-scale mining industry. However, most migration from Brazil is illegal and goes unrecorded, preventing quantitative tests of its impact. Neither do longitudinal data on gold production exist, either per miner or for Suriname as a whole.

As a substitute, I use the Chow test to find out whether the introduction of technology coincided with a change in the driving forces of the gold rush (Gujarati, 1995, pp. 263–265). The Chow test examines whether a function undergoes a structural change between two time periods. In other words, the test detects whether the predicted relationship between the mining population and macroeconomic factors differs before and after a selected year t. I selected the year 1986 as the turning point because this year marks the beginning of 6 years of civil war in Suriname. The civil war was fought between the military government and Maroon insurgents and destroyed much of the economic, social, and physical infrastructure in the Suriname interior (Polimé and Thoden van Velzen, 1992). According to gold miners, Brazilians and improved mining equipment began entering Suriname around the time that the war broke out.

I excluded several variables that have encouraged mining elsewhere, but that are irrelevant in the Suriname case. I omitted road quantity because no significant roads have been constructed in the Suriname forest over the past three decades. One might also expect that the discovery of new

Table 1
Definitions and summary statistics of the variables in the WLS model

Variable	Definition of the variable as presented in the model	*N*	Mean	Std	Range
$Miners_t$	Natural log of the estimated number of active gold miners in the local Ndjuka population, corrected for attrition	29	48.4	40.5	1–123
Price of gold	Natural log of the real price of gold per troy-ounce in Suriname guilders (base = 1998)	29	37 427	82 385	282–247 481
Price of oil	Natural log of the real price of oil per barrel in Suriname guilders (base = 1998)	29	7475	4743	557–16 862
CPI	Natural log of the consumer prices for all items (base = 1998)	29	13.79	31.11	0.15–100.00
Unemployment	Percentage unemployed in the economically active population	27	9.75	6.90	0.9–22.7
GDP per capita	Natural log of the per capita GDP in Suriname guilders, adjusted for inflation (base = 1980)	29	3547	406	2889–4294
Year	$Year_t$	29			1970–1998

Summary statistics are for non-logged values.

deposits attracts new miners. This explanation does not hold for Suriname because the Ndjuka have mined gold and been boatmen and guides on governmental prospecting expeditions for centuries. Oral histories and the remains of past mining reveal a historical awareness of the presence of gold deposits in places where mining occurs today. Neither is the price of mercury likely to be of influence. In the mining operations that I visited, mercury accounted for only 1–2% of monthly production expenses.

The Durbin Watson test was indecisive about the presence or absence of positive first-order serial correlation ($d = 1.00$, $P < 0.01$). Alternative tests suggest that first-order autocorrelation poses no threat to the regression.[1] The small sample size ($N = 29$ years) reduces the power of the statistical tests.

3.3. Explanatory variables

Macroeconomic data were obtained from International Monetary Fund Statistical Yearbooks (IMF 1975–1998), the Suriname General Bureau of Statistics (ABS, 1997, 1998, 2000), the US Geological Survey (pers. com, February 1998), the US Energy Information Administration (EIA, 2001), and several electronic sources. The US Gross Domestic Product Implicit Price Deflator was used to correct the international commodity prices for inflation (Economagic.com, 1999).

The prices of gold and oil are included as the natural log value of the inflation-adjusted price of the commodity in Suriname guilders (base = 1998). Consumer prices are included as the natural log value of the Consumer Price Index with the base year 1998 (ABS, 2000). Unemployment expresses the percentage unemployed of the economically active population (ABS, 1997). The Suriname General Bureau of Statistics generously compiled and sent me time series for the inflation-adjusted per capita GDP (pers. com, July 2001). Definitions and summary statistics of the variables appear in Table 1.

4. Results

The estimated percentage of gold miners in the Ndjuka population fluctuates until the early 1980s (Figs. 2 and 3). Around that time the projected mining population begins to increase rapidly. The stagnation between 1986 and 1990 probably reflects the inaccessibility of the interior during the initial years of the interior war. Since 1990, the proportion of Ndjuka gold miners in the population has grown continuously.

[1] An OLS regression with a Cochrane–Orcutt correction for autocorrelation did not generate substantially different model outcomes. A graph of the residuals from the OLS model against Year shows no obvious patterns in the residuals over time. These findings support the idea that autocorrelation does not pose a serious problem to the regression results.

Table 2 summarizes the regression results. The presented model explains 80% of the observed variation in the mining population ($R^2 = 0.80$). I did not find the expected relationship between international prices of gold and the Ndjuka participation in gold mining. Gold prices were negatively related to the number of gold miners, but the effect was statistically weak ($\beta = -1.34$, n.s.). Also contrary to what was predicted, oil prices were positively related to gold mining; each percent increase in the price of oil was estimated to cause a 1.7% increase in the local number of gold miners ($P < 0.05$). I cannot find a logical explanation for this effect and suspect that it is spurious.

Two of the three variables representing the state of the national economy, CPI and unemployment, were statistically significant and had the expected positive signs. Each percent increase in consumer prices was predicted to cause a 0.4% growth in the mining population ($P < 0.05$). The estimated effect of unemployment is small; each percent increase in unemployment was estimated to cause a 0.2% increase in the number of local gold miners ($P < 0.05$). GDP per capita had a statistically and socially negligible effect on changes in the mining population ($\beta = 0.33$, n.s.). The Chow test identified a structural break in the mining function in 1986; the statistical significance of this effect is moderate ($F = 2.24$, $P < 0.10$).

5. Discussion

5.1. International commodity markets

Local extractive activities can have severe ecological impacts and are often beyond the control of national authorities. Hence, understanding the forces that encourage extractive booms is crucial to the success or failure of policy efforts aimed at decreasing local people's propensity to participate in such booms. The evidence presented in this study does not support the hypothesis that rising global prices of gold have sparked the Suriname gold rush. A visual presentation of the trends in gold prices and mining activity underscores this conclusion (Fig. 2).

Interview data confirm the statistical findings. When I asked people why they had become gold miners, not one person mentioned gold prices or an expectation of striking it rich. Most miners found mining unpleasant, tedious, and physically

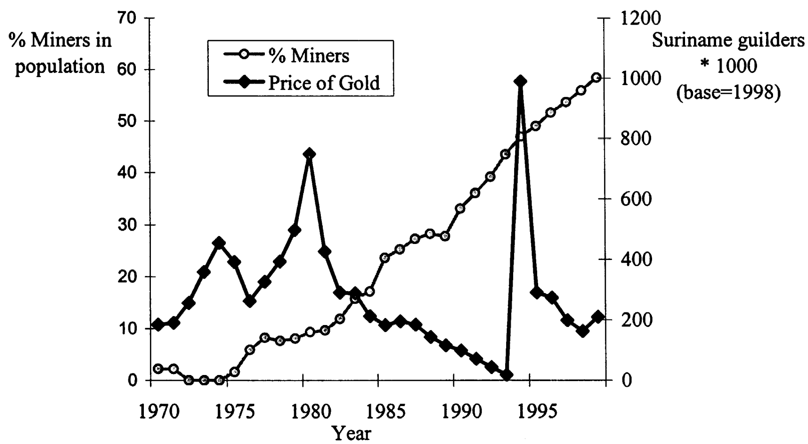

Fig. 2. Trends in the price of gold and the estimated percentage of active gold miners in the local population, 1970–1998. Source of gold price data: US Geological Survey (perscom, February 1998). Most recent monthly rates that were used for 1998–August 1999 are available at http://www.kitco.com/gold-history. For a long time, the Breton–Woods agreements (1944) fixed the price of a troy-ounce (31.1 g) of gold at US $35. The end of the agreement caused a rise in gold prices, which reached a record peak of US $850 per troy-ounce in 1980. US open market rates differ from Suriname in-country rates due to their dependency on exchange and inflation rates. The low prices in the early 1990s are due to an artificially kept low exchange rate, and rise in 1994 when this rate is corrected from 1.8 to 134.1 Sfl/US$.

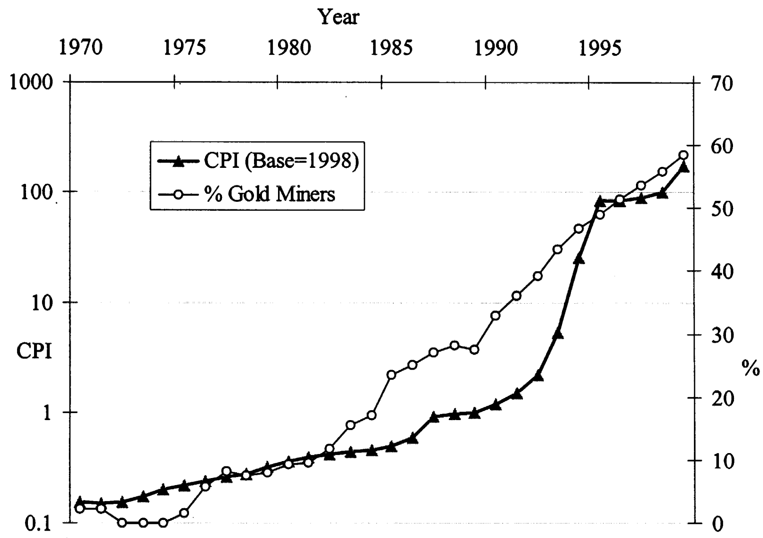

Fig. 3. Consumer price index, annual average (1998 = 100), and the estimated percentage of active gold miners in the local population, 1970–1998. Source of CPI data: Suriname General Bureau of Statistics, Section Consumer Price Indices (ABS, 2000). Note that the scale for the consumer index is logarithmic.

demanding, and despised the isolation from one's family, community life, and urban civilization (Heemskerk, 2001). In their experience, however, unskilled jobs in town generated no more than about US $60 per month, which was well below the bare subsistence minimum. Given that half of the miners in the sample earned at least US $400 per month, mining wages compared positively not only to the low end of the wage scale, but to economic alternatives in general. The annual average per capita GDP in the 1990s was below US $2000, which is less than a mining income if one were to mine just 6 months out of the year. These observations suggest that mineral prices would have to drop to half their current levels before alternative income generating activities in Suriname's formal economy may compete with incomes people can expect in gold mining.

It has been suggested before that informal miners may be less sensitive to changes in mineral prices than large-scale mining companies (MacMillan, 1995), but this study is the first to empirically support that argument. I speculate that the unequal response of local miners and multinational mining firms to commodity prices derives from the different scales at which they make decisions. Small-scale gold miners consider a variety of local factors, including the cost of living, the availability of other economic opportunities, and wages. For large companies, international price markets may be the most important factor determining whether the exploitation of

Table 2
Regression results for the WLS model predicting change in the number of gold miners in the local population, 1970–1998

Variable	*β*	*t*
Ln (real price of gold in Suriname guilders)	−1.34	−1.68
Ln (real price of oil in Suriname guilders)	1.70*	2.37
Ln (CPI)	0.42*	2.14
Unemployment	0.19*	2.78
Ln (GDP per capita)	0.33	0.37
Model Summary		
N	29	
R^2 (Adjusted R^2)	0.80 (0.76)	
Durbin–Watson's *d*	1.00	

Regression is weighted by year, and the constant is repressed. Dependent variable is Ln (Miners$_t$). All reported coefficients are standardized beta values.

* Significant at the 0.05 level.

deposits is worth the investment. Hence, it could happen in the late 1990s that a transnational mining agglomerate in Suriname decided to delay further gold exploration activities until the price of gold would recover, while the population of local miners kept growing. Future research may reveal whether this pattern characterizes the development of extractive industries other than gold mining as well.

My analysis and observations in Suriname suggest that the movement of people and knowledge across borders changed the face of the small-scale mining industry. The break in the mining function in 1986 suggests that, among other factors, the migration of Brazilian miners to Suriname exhilarated the gold rush. Ndjuka miners recognize that Brazilians have advanced small-scale mining technology, yet it was not possible to empirically test the relation between technological change and the mining boom.

5.2. National economic recession

The data lend support to the hypothesis that national economic recession has encouraged small-scale gold mining. The relation between national level unemployment and local level mining is not straightforward. Between 1970 and 1988, mining activity increased as national unemployment rates rose from around 3% in the 1970s to peak at 22.7% in 1988. When unemployment rates fell after 1988, however, the number of people entering mining continued growing.

I suspect that the above observation reflects the disadvantageous position of Ndjuka on the national labor market, a position that worsened during the civil war of 1986–1992. During this period of political violence, Ndjuka villages were destroyed, rural education and health care were eliminated, poverty increased, and negative ethnic stereotypes of Ndjuka intensified (Polimé and Thoden van Velzen, 1992; Healy, 1996). As a result, Suriname citizens other than Ndjuka may have been in a better position to occupy the jobs that became available after 1988. The result of the Chow test probably partly captures the reduction of livelihood options due to the interior war, and the marginal position of the Ndjuka in its aftermath.

In making decisions about participation in gold mining, the decreasing purchasing power of formal wages may have been more important than the absolute lack of jobs. The depreciation of wages is primarily a product of monetary devaluation and rising consumer prices. Expressed in Suriname guilders, the cost of living increased ten-fold between 1990 and 1997 (Fig. 3). The effective size of the CPI may appear to be small; each percent increase in consumer prices is estimated to cause a 0.4% growth in the mining population. However, with consumer prices increasing 102% per year between May 1998 and May 1999 (IMF, 1999), continued rapid growth of the mining population can be expected in the absence of economic restructuring. The parallel growth of consumer prices and the mining population (Fig. 3) favors the national-drivers hypothesis.

It is worth pointing out that this interpretation of the data reverses the 'Dutch disease' model (Corden and Neary, 1982). It seems that the Suriname resource boom did not cause economic recession, but rather that economic volatility triggered the gold mining boom. In fact, the mining sector may be a stabilizing factor in the current Suriname economy by serving as an outlet for the country's poorest people. These observations emphasize my earlier comment that the drivers and implications of a resource boom depend on the scale at which the resource user makes decisions and operates.

6. Conclusions: economic-ecological feedback loops

I present a simple visual model to summarize the relations and feedback loops between the economic drivers and ecological consequences of small-scale gold mining that were discussed in this paper (Fig. 4). The model demonstrates that rising consumer prices and unemployment encourage small-scale gold mining both directly and indirectly. Directly, high prices increase daily expenses and hence the need for hard currency, such as US dollars or gold. In addition, high costs of urban housing and services make it economically benefi-

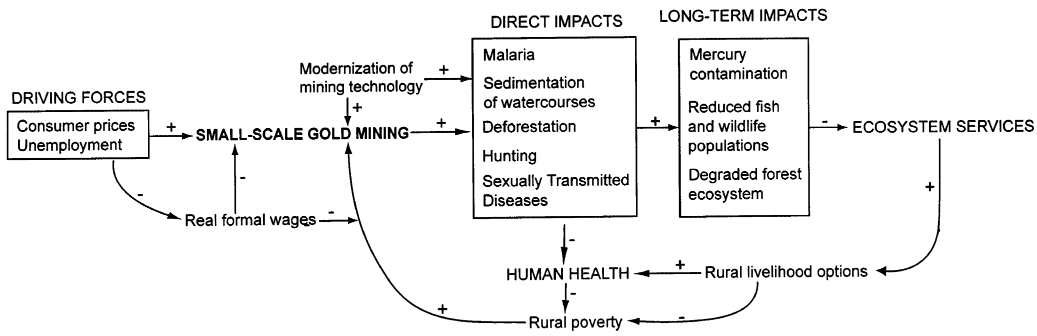

Fig. 4. Feedback loops between economic drivers and ecological impacts. Arrows indicate links between processes and the signs indicate their direction, with a plus (+) indicating a positive relationship and a minus (−) a negative relationship. The model articulates that more mining will increase the scale and intensity of short-term ecological impacts, and hence worsen the long-term ecological consequences of mining. These long-term ecological impacts negatively affect ecosystem services, which in turn will jeopardize rural livelihood options. By degrading human health and increasing rural poverty, environmental degradation may encourage small-scale gold mining.

cial to work in the forest. Unemployment decreases the availability of jobs other than mining.

Indirectly, high consumer prices and unemployment decrease the real value of wages in the formal sector, which increases the comparative profitability of mining. In real terms, wages in the mid-1990s were only half of what they were in 1980 (ABS, 1997). Real wages in construction and government service, jobs in which Maroons are over-represented, reached respective lows of 12 and 30% of 1980 wages. The impoverishment of households that rely on devalued formal wages may provide incentive to previously inactive household members to enter mining, including children and elderly. The model further indicates that the modernization of mining technology both stimulates small-scale gold mining and aggravates its impacts.

Small-scale gold mining has a range of immediate and delayed ecological consequences that are discussed in Appendix A. Mining-related degradation of ecosystem services threatens the livelihoods of people who depend on the forest for food and other basic needs. The reduction of fish and wildlife populations, due to habitat destruction and hunting, may decrease the protein intake of people who live near mining areas. Fish are the most important source of fresh protein in forest communities.

Impoverished diets may aggravate the health effects of mercury contamination, malaria, sexually transmitted diseases, and environmental pollution. At the same time, the rural health care system is not adequately equipped to mitigate these health effects. I anticipate that the deterioration of public health in Suriname's interior will have high social and economic cost by increasing the frequency of disease, increasing child mortality, and lowering life expectancy. The model's feedback loops suggest that as rural poverty increases, more people may turn to gold mining for a living (Fig. 4).

6.1. Ecological management

Suriname's economic development and the exploitation of its natural resources are intrinsically linked. If the Suriname government wants to discourage small-scale gold mining and the environmental impacts it produces, economic stabilization appears to be a first requirement. In addition, protection of Suriname's rainforest would benefit from the improvement of public services to forest peoples. Better quality elementary education, for example, may improve the labor market access of Ndjuka and hence reduce the pressure to become miners. Cases elsewhere suggest that this argument has validity beyond Suriname. Gold and diamond mining in Brazil, Angola, and Sierra Leone, for example, boomed in times of high inflation and socioeconomic stress. The California gold rush may also have reached its historic proportions in part due to meager economic opportunities in other parts of the United States in the mid-19th century.

Given that economic restructuring will take years, ecological conservation may benefit from the promotion of less damaging mining techniques that can be implemented immediately. Several methods exist that minimize or eliminate the use of mercury to extract gold (Veiga et al., 1995). Retorts that allow for mercury recycling are readily available in Paramaribo's mining stores and cost about US $200. Even though this price is only a fraction of production expenses and most miners know of the existence of retorts, few mine operators are currently using them. Perhaps more aggressive introduction campaigns or apparent symptoms of mercury contamination will motivate the widespread adoption of such tools. Programs in Brazil have suggested several other strategies for more sustainable mining (Cleary and Tapajós Garimpeiros, updated). For example, training miners to be better prospectors can decrease the amount of forest without gold deposits that is being cut while raising mining profits. Another potential policy would be to reduce disease transmission by providing free condoms and re-establishing malaria control in the Suriname interior.

Until the quality-of-life of forest peoples improves, these people may have few incentives to worry about the ecological impacts of gold mining. Given its precarious economic position, I do not expect that the Government of Suriname will prioritize financing more sustainable small-scale gold mining. International conservation groups, on the other hand, could play an important role in promoting a more sustainable future for the Amazon forest and its inhabitants.

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Appendix A. Ecological consequences of small-scale gold mining

Small-scale gold mining severely impacts the ecology of Amazonia. The recent onset of the mining boom in Suriname means that long-term effects are not yet apparent, yet local observations and studies from elsewhere in the Amazon suggest substantial ecological impacts. Gold miners' release of mercury into the environment has particularly alarmed the media and scientists, and drawn international attention to the Amazon gold rush (MacMillan, 1995). Miners use mercury, which amalgamates with gold, to facilitate the separation of gold from other soil particles. Gold is retrieved when mercury evaporates after heating the amalgam (Peterson and Heemskerk, 2001).

When people handle or inhale inorganic mercury, it is usually discharged from the body through the urine. More serious is mercury contamination via the consumption of polluted fish. Inorganic mercury transforms into a highly toxic state, called methyl-mercury, when it leaches into rivers, is absorbed by ground-feeding organisms, and moves up the food chain through carnivorous fish. Estimating how much mercury miners release into the environment is difficult, as is estimating its net effect on human and ecosystem health. In interviews, miners said that they used about 1 kg of mercury per kg of gold extracted. Given gold production estimates of 10 000 to 20 000 kg per year and low mercury recycling rates, over 10 000 kg of mercury may be released into Suriname's air and aquatic ecosystem per year. This estimate is probably conservative, given that mercury imports are estimated at 20 000 kg per year (Pollack et al., updated).

Measures of the proportion of mining-related mercury that ends up in the aquatic ecosystem may be biased by the natural release of mercury from Amazon soils (Pepall, updated). Despite such confounding factors, it is evident that mercury levels in people, fish, and water nearby mining areas exceed mercury levels in control areas (Akagi et al., 1995; De Kom et al., 1998). The resemblance and mutual reinforcement of the symptoms of mercury intoxication, chronic malaria, and alcoholism, complicate determining the net health effects of increased mercury levels. Nevertheless, existing evidence suggests that particularly chronic mercury pollution damages the central nervous system of fish consumers near mining areas, with pregnant women and infants being most at risk (Guimarães et al., 1994; Akagi et al., 1995; Lebel et al., 1995).

Among the most immediate impacts of small-scale gold mining is the uncontrolled spread of malaria. Open pits with standing water constitute a fertile habitat for disease-carrying mosquitoes. The frequent movement of miners facilitates malaria transmission, and the haphazard intake of medications breeds drug-resistant malaria strains. Failing public health care aggravates the situation. Due to inadequate government funding, forest clinics are short of beds, personnel, equipment, and medications. In the late 1970s, infectious diseases such as malaria were virtually exterminated in the Suriname interior. Today, it has become one of the most common and deadly diseases among forest populations.

Mining affects the overall quality of the aquatic ecosystem when tailings of mining operations are discharged into rivers and creeks. According to some researchers, miners spill two cubic meters of sediments into watercourses for each gram of gold extracted (Douroujeanni and Padua, 1992, in MacMillan, 1996, pp. 157). With the arrival of more powerful mining equipment, these estimates probably understate sediment spillage today. The limnology of rivers in the isolated Suriname interior is poorly researched, and it is difficult to predict the net effects of sedimentation on aquatic communities. Possible effects include the destruction of fish breeding grounds and habitat, the reduction of oxygen levels, and the inhibition of fish foraging strategies. Increased river turbidity also threatens aquatic fauna other than fish, including two caiman species; *Caiman crocodiles* and *Palaeosuchus palpebrosus* (Mohadin, 1993).

The amount of mining-induced deforestation is small relative to the impact of logging, small-scale farming, or cattle ranching elsewhere in the Amazon. In 1998, Peterson and Heemskerk (2001) assessed the rate of mining-induced deforestation in Suriname as 48–96 km^2 per year, a small fraction of the total area of Suriname rainforest (147 130 km^2). However, the repeated soil turnover and complete removal of roots that accompany mining impede regeneration. After decades, vegetation cover in areas where mining has been concentrated remains qualitatively different from that in nearby old-growth forest. Aerial views reveal long strips of bare ground with virtually no forest recovery that cut through the Amazon forest. Finally, I observed a complete absence of wildlife near mining areas. However, given the paucity of scientific studies on wildlife populations in the Suriname interior, there is no evidence that miners affect wildlife more than people in nearby forest communities.

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