Impacts of mining projects in Papua New Guinea on livelihoods and poverty in indigenous mining communities

Londari Yamarak^{1,2} · Kevin A. Parton¹

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Abstract

In Papua New Guinea (PNG), mining has been surrounded by controversy related to its environmental and social impacts for several decades. In this context, the research reported herein is an investigation of the way in which mining has impacted on poverty in two large mining regions at Ok Tedi and Porgera. We surveyed 609 households, of which 309 were in indigenous mining communities and 300 were in non-mining indigenous communities, across the two regions. To compare these households, logistic regression and propensity score matching methods were used. Based on the sustainable livelihood framework, the analysis focused on four important metrics: the rich–poor ladder to understand the communities’ views of their own affluence, level of education, food eaten in the last 30 days and income satisfaction (or satisfaction derived from a given level of income). The results overall suggest that mining does reduce poverty and improve welfare, but the differences between mining and non-mining villages, such as average level of education, are small. This research work is first of its kind to examine the economic impacts of mining in PNG using the propensity score matching method.

Keywords Mining · Poverty · Non-random effects · Sustainable livelihood framework · Propensity score matching · Papua New Guinea

Introduction

In developing countries around the world, mining can provide substantial economic opportunities that can lead to sustainable growth. However, mining continues to be contentious, as genuinely sustainable development has been shown to be dependent on far more than economic opportunities. Several notable environmental, social and economic problems have resulted from mining operations that have been poorly planned and implemented. This has led to a questioning of the potential for mining to produce sustainable outcomes. Much more these days, mining development is assessed in a multifaceted way in terms of its technical feasibility, economic opportunities, ecological impact and social equity.

As a consequence of different emphases given to these various aspects, there are extremely different views of the effects of mining in developing countries. Pegg (2006) provides a useful summary by comparing the World Bank’s traditional position with that of recent empirical evidence. The positive position is sustained by the following arguments: many of the most advanced countries today became so on the basis of resource extraction; government revenue is generated for use in social development and infrastructure; because mining creates jobs, families have income opportunities that would otherwise be unavailable; such micro-economic developments create a multiplier effect leading to macroeconomic growth; technology transfer into the country is encouraged first through small-scale industries engaged by the mining companies and then generally; and downstream manufacturing industry develops as mineral resources become available.

In contrast, there is a plethora of empirical analysis that suggests that this view is overly optimistic and that a number of the above linkages are questionable. Ross (2001) found that countries dependent on minerals and relying on mineral exports tend to have higher levels of inequality. Also, mining often fails to provide jobs for the poor, who are

✉ Kevin A. Parton
kparton@csu.edu.au

¹ School of Management and Marketing, Charles Sturt University, Bathurst, NSW, Australia

² PNG University of Technology, PMBS, Lae, Morobe Province, Papua New Guinea

Fig. 1 The conceptual framework.

Adapted from Adjei (2007) based on the sustainable livelihood framework by Scoones (1998). Source: XXX (unpublished PhD thesis [name of author is suppressed to preserve the anonymity of the review process])

unskilled. In the case of each given country such as Papua New Guinea, empirical research is necessary to investigate whether mining has led to a reduction in poverty. Hence, a primary objective of the study was to estimate the impact of mining on poverty in the significant mining locations of Ok Tedi and Porgera. With this objective in mind, the sustainable livelihood framework (Scoones 1998) was used as the conceptual basis. This is described in the next section. The data that forms the basis of the study and a description of the case study region are presented in the following two sections. Then, the propensity score matching method is outlined. Results and discussion and then conclusions are the subjects of the final two sections of the paper.

Perspectives on poverty and mining in Papua New Guinea

There are many definitions of poverty (Alkire et al. 2015). Scoones (1998) developed the sustainability livelihood framework (SLF) to explain the linkage from people to their livelihoods. This has become central to understanding various conceptual and methodological issues in rural poverty alleviation. It captures issues such as rurality, poverty, education and environmental issues. The SLF focuses on discovering the combination of livelihood resources that support a given livelihood strategy.

A sustainable livelihood is a means for the marginalised to achieve a sustainable improvement against the indicators of poverty (Ashley and Carney 1999). Although it is common for individual researchers to vary the precise definition of the SLF, many draw on the work of Chambers and

Conway (1992). From their perspective, a livelihood is a means of living consisting of assets (including both material and social resources) and activities, and capabilities for their use. A sustainable livelihood is one that, when facing stresses and shocks, can maintain or enhance its assets, while not compromising the natural resource base. The SLF has been applied at different scales from the household to country level. It focuses attention on the main factors that affect the livelihoods of the poor, and on interventions that enable them to use and expand their capabilities (Kollmair and Gamper 2002). Hence, the SLF is a conceptual framework that can be applied at various scales to analyse the links from access to resources and various economic and social activities to poverty and its alleviation using both tangible and intangible assets (Hussein 2002; Adjei 2007).

Figure 1 shows the SLF containing the basic elements mentioned above. Five types of capital are central to the process of generating livelihood outcomes: natural, human, social, physical and financial. Their aggregate impact is on transforming structures and processes, and they are themselves impacted by various vulnerabilities. The five capitals define the possible livelihood strategies, and these lead to the livelihood outcomes. These are the components that determine whether or not a livelihood is sustainable (Essacu 2018). Together, they are the livelihood resources (the capitals) and livelihood strategies that determine the level of poverty. In a practical sense, they are the stocks, food and cash to meet basic needs. This framework analyses the situation of people with different assets and/or capabilities, in pursuit of their livelihood goals (Adato and Meinzen-Dick 2002). For example, in the context of mining in Papua New Guinea (PNG), some farmers may be forced from their land

Fig. 2 Key linkages between mining and poverty reduction. Adapted from Weber-Fahr et al. (2002, p. 447). Source: XXX (unpublished PhD thesis [name of author is suppressed to preserve the anonymity of the review process])

and impoverished as a mine is developed. Nevertheless, there still could be a sustainable outcome perhaps involving some form of compensation and/or training. This would enable some to reorganise their farm to produce fruit and vegetables for new thriving local markets and others to work at the mine.

Thus, new mines impact on the asset base that people use to build their livelihoods. Mines also affect institutional processes and structures. Rural populations in many developing countries have achieved substantial income gains from mining (Adjei 2007; Weber-Fahr et al. 2002). Indeed, the World Bank has proposed a number of best practices for achieving sustainable outcomes (Pegg 2006). However, livelihoods can also be threatened by mining investments if such practices are not followed. Applying the SLF, Weber-Fahr et al. (2002) observed that mining has both a cross-sectoral and systemic impact, and they developed the model of mining–poverty reduction linkages of Fig. 2. This shows that poverty is reduced through interlinked economic opportunities, improved capabilities, enhanced security of the poor and empowerment of rural people. By this means, the poor are placed at the centre of economic development analysis. Using this framework as a basis, this study explores the impact of mining on the livelihoods of indigenous peoples of two regions of PNG.

Considering first economic opportunities, according to the Papua New Guinea Extractive Industries Transparency Initiative (PNGEITI), in 2020, PNG's extractive industries contributed 89% to exports, 29% to GDP and 10.1% to the government revenue. In 2018, the largest sources of government revenue from the extractive industries included corporate income tax, salary and wage tax, dividends and royalties (PNGEITI 2020). It was forecast in 2018 that the PNG economy would grow by 2.1% in 2020 (ADB 2018). However,

the current forecasts by ADB indicate otherwise. PNG's GDP growth rate is expected to be −1.5% in 2020, and 2.9% in 2021 (ADB 2020). Perceptions of corruption and fiscal instability also beset the country, and currently, there is the impact of COVID-19. Many of these experiences in PNG are not unlike those of the 22 countries with a similar level of mining exports that had an average annual GDP per capita growth rate of −1.1% between 1990 and 1999 (Weber-Fahr 2002). This could mean poverty exacerbation rather than poverty reduction for countries that depend on mining. So, it is necessary to look more closely at such economies.

With the appropriate institutional linkages, economic opportunities can be presented to the rural poor. By taxing the mining operations, revenues can be used to improve infrastructure such as schools, health facilities and roads. Welfare and other poverty reduction interventions become immediately possible (Weber-Fahr et al. 2002). Indeed, the four largest mining companies in PNG have made substantial contributions to government revenue, amounting to 17.2% of the PNG government's total revenue and grants over the relevant period (Callan 2013, p. 3). Hence, mining opens up economic opportunities at the state level in PNG. Other evidence is needed to confirm whether this largesse has been distributed to the poor at the community level.

Baxter (2001) argued that the PNG government needs a greater willingness to support its communities for such mining revenues to have a wide impact. The legal and payment system is complex, opaque and one sided, and there is no credible method of tracking payments to and from stakeholders (Johnson 2012). Moreover, while the communities should be the beneficiaries of PNG's mining and mineral wealth, the combined effect of the mining investment and the adapting strategies of individual households could lead

to severe detrimental outcomes for the overall community (Johnson 2012).

Another economic opportunity is through job creation. By providing employment opportunities, mining can also have a positive impact by improving the capabilities of the poor (Weber-Fahr et al. 2002). However, the capital-intensive nature of mining limits the extent of job creation, so that there is only a small increase in employment, and much of this may be filled from skilled and semi-skilled workers from outside the region. Hence, the ratio of jobs created to revenue generated by mining is often small. In PNG, mining extraction has become increasingly important to PNG's macroeconomy and in absolute numbers to domestic employment. This dependency on mining is highlighted by the increase in domestic employment in exploration, construction and extraction, growing from 12,000 people in 2004 to 30,000 people in 2010, though the number of jobs per dollar of mining investment is low (Filer et al. 2012).

Improved capabilities of the poor are a second theme of the mining–poverty reduction framework of Fig. 2. Weber-Fahr et al. (2002) argue that over the medium and long terms, training provided for miners and other skilled contract workers is likely to have positive spill-over effects on the regional workforce. Mining companies also provide training for small enterprises that supply them with goods and services, bringing them up to international standards in terms of quality and reliability. There are also instances of direct investment in education and health, often provided initially for the mine's employees, but then extended to the general public, investment in local government capacity, investment in community-related services or activities with universal access, best accomplished in conjunction with the local authority. Indeed, such community investments would be expected as a component of the corporate social responsibility of mining companies. However, some studies have shown dependency on minerals resources being correlated with lower spending on education (Gylfason 2001). Across 52 countries, he showed that a 5% increase in the share of natural capital was associated with a 10% decrease in secondary school enrolment (Gylfason 2001, pp. 852–853). In summary, a mining operation has the potential to positively improve the capabilities of the poor as a group, but such an improvement could be small and is by no means certain.

The third area of the framework of Fig. 2 is security. As mentioned above, the mining companies can contribute to improved nutrition, education and health care in a community to reduce risk and vulnerability. For example, at the Porgera gold mine in PNG, most of the children of the former landowners have better education opportunities overseas and improved employment prospects. These landowners and their families have also received medical insurance. Mining also improves the standard of living for these people through better paid jobs. However, unless such benefits are widely

spread, many people continue to face security risks. In commenting on mining generally in developing countries, Starke (2016) lamented the loss of existing livelihoods and the damage to the environment and culture, together amounting to reduced security. There is a clear need to better redistribute tax revenues to local governments and to build capacity at the community level (Walser 2000).

Also in relation to security, as well as the risks of instability of employment and income, mining can despoil the natural environment and expose the local population, particularly the poor, to serious health risks. These can take the form of work injuries, exposure to infectious diseases and environmental hazards. According to Mudd et al. (2020), in PNG, mine wastes are approved to be discharged to rivers or oceans on a large scale, leading to widespread environmental and social impacts. For example, contamination of the Ok Tedi River results in diseases for the local people. Tailings from the Ok Tedi mine have been discharged into the river since the mid-1980s (Banks 2002), and Campbell and Beardall (2019) found that the mining waste released from Ok Tedi to the Fly River has recently increased. Porgera faces similar risks (Human Rights Watch 2010).

Although it would be expected that large-scale mining investment would bring jobs, business activities, roads, schools and health clinics to remote and previously impoverished areas, the outcome can be the opposite with mining investment benefiting only a minority, resulting in social tension and sometimes violent conflict. This can give rise to cultural instability and political instability.

Empowerment of local communities is the fourth aspect of the mining–poverty reduction framework of Fig. 2. There is a risk that the interests of local communities will be overlooked in the process of establishing institutional arrangements. The resulting limited engagement between communities and mining companies and the government can give rise to livelihood outcomes that are unsustainable (Johnson 2012). This risk can be reduced by involving local people in decision making to improve community welfare (Weber-Fahr et al. 2002), and thereby creating institutional arrangements that forge a form of economic growth that empowers the rural poor and ensures that they participate in the growth process. Participation can be enhanced by communities if they are able to mobilise their own resources, and this depends greatly on the relative power and property rights given to the mining companies by the government (optimistically in consultation with the local communities) (Doyle and Perez-Alaniz 2017; Adams et al. 2018). Hence, the empowerment viewpoint suggests that poverty reduction can only be enduring when economic development involves local communities controlling their own resources to achieve security and sustainability of livelihoods.

Good communication is vital to the empowerment process. Local participants in the mining project must be

Table 1 Mining–poverty reduction linkages and their measurement variables

Concept derived from mining–poverty reduction linkage and SLF	Measurement variable	Survey questions
Economic opportunities	Inside capital	Does your household have TVs, VCD/DVD players, refrigerators, freezers and cars/trucks?
Capabilities	Human capital	What is the highest educational qualification that you have completed?
Security	Food eaten in the last 30 days	Which of these statements best describes the food you have eaten in the last 30 days?
	Square meals in 12 months	How often did you eat 3 “square meals” (full stomach meals) each day in the past 12 months?
	Income satisfaction	How often does your income satisfy your everyday needs? Would you say that you have: (1) not enough money, (2) just enough money, (3) enough money or (4) more than enough money?
Empowerment	Village participation to help	In the last 4 years, have you personally done/observed any of the following things? (1) participated in an association, (2) regarded the villagers as honest and can be trusted, (3) considered the villagers to be willing to help and support others or (4) been supported by the community when your household or other community members have a problem
	Information volunteering	In the last 4 years, have you personally done any of the following things? (1) media interview about an issue or problem, (2) involvement in an information campaign or (3) volunteering to help or support the community
Reduced poverty levels	Rich–poor ladder	Please imagine a 9-step ladder where on the bottom, the first step, stand the poorest people and on the highest step, the ninth, stand the rich. On which step are you today?

engaged in a transparent decision-making process involving public consultation and full disclosure of relevant information (Weber-Fahr et al. 2002). Then, the likely impacts of the mining development on the local people will more readily be understood, and they are more likely to support it. Also, good communication itself can enhance the relationship between the communities and the mining companies, explain how the various parties can participate, augment local capacity building and lead to more sustainable growth outcomes (Weber-Fahr et al. 2002). Conversely, corruption is likely to go hand-in-hand with poor communication that facilitates the accumulation of economic resources and (covert) power in the hands of the few, disempowering local communities. Once created, such an environment can entrench poverty.

To summarise, Fig. 2 provides a framework of linkages that is the basis of the empirical work of this study. In each of the linkages, there is a two-way relationship. Thus, for example, if capabilities of the local community are enhanced, this can lead to both economic opportunities and empowerment. At the macroeconomic level, through taxes and royalties, mining can generate large revenues that can support public investment to enhance the wellbeing of the poor (Pegg 2006; Weber-Fahr et al. 2002). At the microeconomic level, employment opportunities and incomes for the local people can be created by mining. The incomes generated will be spent and, through the multiplier effect, support more incomes, leading to a process resulting in sustainable local communities (Weber-Fahr et al. 2002). Nevertheless,

this ideal may not be achieved because of the imperfections, considered above in the four critical aspects of the model of Fig. 2. Such issues have been observed throughout the developing world and in PNG.

Data

In order to operationalise a model of the relationships of Fig. 2, particular items of data were collected. Table 1 shows how the different components of the relationships were measured using eight variables. (The definitions of these variables are provided below.) Hence, assessment of the progress of the two PNG mining communities was made using these variables to measure the five key aspects of the mining–poverty reduction linkages of Fig. 2: economic opportunities, capabilities, security, empowerment and level of poverty.

As shown in Table 1, inside capital is used to represent the first component of the mining–poverty reduction linkage, economic opportunities. It consists of televisions, VCD/DVD players, refrigerators, freezers and cars. The villages were classified as mining or non-mining depending on their distance from the mine site. Mining villages were within 15 km of a mine, and non-mining villages were at least 40 km away from one.

Human capital is basically the education level of the households within both mining and non-mining regions in

OK Tedi and Porgera and is used to measure the second component of the mining–poverty reduction linkage, capabilities. Mining investment has brought about increased investment in human capital. Human capital questions asked if there were any adults living in that household and if they had any educational qualifications. In the analysis of these variables, it was hypothesised that education levels would be higher in mining households than in non-mining households.

Three variables were used to measure the third component, security: food eaten in the last 30 days, square meals in 12 months and income satisfaction. Food eaten in the last 30 days refers to the quantity that the household members eat in a month on average of various kinds of food. It measures “enough of the kinds of food they wanted to eat, or enough, but not always the kinds of food they want, or sometimes not enough or often not enough” within that 30-day period. Food eaten in 30 days is a variable used to measure the security of the food eaten in the communities, both mining and non-mining. Meanwhile, square meals in 12 months is a variable used to measure the quality of the food eaten in the communities. It measures the quality of the food and the times these types of meals were taken. For example, how often do they have square meals each day in the past 12 months. Is it always, often, sometimes, rarely or never? Most indigenous communities do not have access to full meals for breakfast, lunch and dinner every day. The foods in most meals in the villages are high in sugar content and high in carbohydrates and are low in protein (Bourke and Harwood 2009). A high proportion of children become malnourished and die (Bourke 2001; Bourke and Harwood, 2009).

Income satisfaction is a variable that concerns the income security and whether the household income was enough to take care of the household’s responsibilities and everyday needs. Income security is an important variable and may impact upon the indigenous villages and their livelihoods and poverty. Income and employment status are often considered inappropriate as dependent variables in studies of the impacts of various exogenous influences on poverty and wellbeing in PNG. Edmonds et al. (2018) use yearly consumption per adult equivalent and other variables like having a good roof, whether a household member had a wage job (which was very rare), whether someone in the household engages in subsistence farming and the ratio of school-aged children going to school. In a similar manner, Schmidt et al. (2021a, p. 398) did not use income because a majority of their survey participants were rural households that depended only on “subsistence farming (barter and trade remain common practice in rural communities in PNG)”; less than 5% of households had wage income; close to one-third of households had non-farm enterprises, but income from these sources was highly variable; and few households had any contact with banks. Moreover, Schmidt et al.

(2021b) do not use income as a measure of welfare because rural incomes in PNG are difficult to quantify as most households are engaged in subsistence agriculture; rural cash incomes vary throughout the year and may be difficult for respondents to recall, and wages fluctuate due to seasonal variation in crop prices and demand for labour and other goods and services. Hence, income and employment status are less useful variables than income satisfaction on empirical grounds. They are also less appropriate for conceptual reasons because they do not focus on the broader aspects of economic welfare in the way that income satisfaction does.

To analyse empowerment, the fourth component of the mining–poverty reduction linkage, two variables were used: village participation to help and information volunteering. Village participation to help measures social capital which may reflect indigenous social values and their impacts on the safety net “Wantok system”. Village participation to help is a variable constructed from survey questions related to the following: (1) whether the household member has participated in an association, (2) if the villagers are regarded by the household as honest and can be trusted, (3) if the community or village people are considered to be willing to help and support others and (4) if the community or the village supports your household when your household or other community members have a problem. Village participation to help measures social capital as it involves the community and its social engagement with the people generally. This is an important part of the social safety net where the villagers participate to help each other. However, on the other hand, in mining villages, distressed household members looking for opportunities in mining may have no time to participate in village obligations. Nevertheless, support services in mining villages can be strengthened through the community relations office within the mining company as part of their community service or corporate social responsibility.

Information volunteering is also an aspect of social capital and consists of (1) speaking to the media about an issue or problem, (2) involvement in an information campaign about certain issues and (3) volunteering to help the community. The media outlets within the mining community and the country at large have a great responsibility in informing the people about what is important to their livelihoods. In the mining communities, sharing information with stakeholders is paramount for decision making. This can inform the indigenous people about the changes, improvements and other related news so that suitable actions can be taken where appropriate. The mining company through the community affairs department is responsible for mining affairs, while leaders in the villagers are responsible within their communities.

Finally, the rich–poor ladder is a variable elicited in the survey questionnaire to measure overall poverty levels within the mining and non-mining communities, the fifth

Case study area and sampling approach

The sample frames for the mining households at Ok Tedi and Porgera were provided by the two mining companies. The sample frames for the non-mining households were sourced from the village elders and councillors. Then, random samples of households were drawn for each

location/type (Ok Tedi or Porgera/mining or non-mining). By employing Cochran's sample size calculation formula (based on a 90% confidence level and 5% margin of error) and treating each location/type as a separate sample, an acceptable sample size is 291 (Bartlett et al. 2001). Financial constraints restricted the sample size to about 150 in each location. This resulted in a 90% confidence level and a 6.5% margin of error. A sample of 609 respondents was taken. In the Ok Tedi District, 153 were mining household respondents and 149 were non-mining; in the Porgera District, 156 respondents were mining households while 151 were non-mining. In the statistical analysis, differences between means were tested using *t* tests, and differences between categorical distributions were tested using chi-square tests.

Table 2 provides a demographic and socio-economic description of the sample. The age distributions of household heads were similar for mining and non-mining villages in both locations (statistically insignificant). The highest average age was 46.22 years from the Porgera mining region while the oldest household member interviewed was from the Ok Tedi mining region (83 years old). As in many parts of PNG, the household heads in both locations were mostly males. In the sample, there was a slightly higher proportion of female household heads in Porgera, but this difference was not statistically significant.

Mining operations usually provide education for children of the mining villages, and this is reflected in both Ok Tedi and Porgera where over 76% of children in the mining households have attended school and many have progressed further onto colleges and have attained qualifications that have enabled them to work in the mining and other modern sectors. On the other hand, Ok Tedi non-mining households indicated that almost 37% have never been to school, while in Porgera, the figure was over 60%. The differences in education participation between the mining and non-mining households were statistically significant (for Ok Tedi, $p < 0.006$, and for Porgera, $p < 0.001$), as was the difference between the non-mining households of Ok Tedi and Porgera ($p < 0.02$).

The modal value for the number of productive adults per household (ranging from 1 to 9) was 2 for both mining and non-mining households in both regions, and the distributions of the number of productive adults per household were similar for each region and village type. Furthermore, the survey results indicate that a majority of people in Ok Tedi and Porgera districts have reasonable size properties.

In both Ok Tedi and Porgera, the mining household members had their food secured (as measured by enough food of the type they prefer) and the quality of their food was maintained (as measured by number of 3 square meals over the last year). However, for non-mining communities in both Ok Tedi and Porgera, there was lower food security and at times the quality of their food was not maintained. There

were significant differences between mining and non-mining households for both regions in food eaten over the last 30 days (for Ok Tedi, $p < 0.01$, and for Porgera, $p < 0.05$).

Because of the various issues discussed earlier related to using income as a measure of poverty, the rich–poor ladder was used. Using the data shown in Table 2, a chi-square test confirmed a higher position on the rich–poor ladder for Ok Tedi mining households than Ok Tedi non-mining households ($p < 0.001$). There was a similar significant difference between mining and non-mining households for Porgera ($p < 0.01$). In contrast, the distribution on the rich–poor ladder for mining households was similar in the two regions, and also for non-mining households in the two regions.

In addition to the rich–poor ladder, we also used an income satisfaction variable. The survey elicited how satisfied respondents were with their income. With respect to income satisfaction, as shown in Table 2, there was generally lower income satisfaction in mining households than in non-mining households. This may be related to the high cost of participating in the money economy of the mining villages.

In summary, the descriptive statistics of Table 2 suggest that in both the Ok Tedi and Porgera regions, mining households are more affluent than non-mining households. However, they still feel that it is costly to engage in the cash economy as shown by their lower income satisfaction than in non-mining households. This was the starting point for the quantitative analysis described in the remainder of the paper.

Methods

The propensity score matching (PSM) method used in this study has three main steps. First, a logit regression (Pampel 2000) was applied in which treatment was the dependent variable and the potential confounders are the explanatory variables (Garrido et al. 2014, p. 1705). In the second step, a check is made as to whether there is a region of common support in which the propensity scores of the mining and non-mining households overlap. Then, the third step of the PSM method is to estimate the average treatment effect on the treated (ATT).

Many circumstances are characterised by discrete choices in which selecting one option means that the alternative is unavailable. The most common area where PSM has been applied is in medical treatment, where a patient receives the treatment or does not. In the PNG mining case, a person comes from either a mining village or a non-mining village. This is a situation where we use a dummy variable with the values 1 (meaning a mining household) and 0 (a non-mining household). Apart from simplicity, using the values 1 and 0 leads to the mean of the dummy variable being equal to the proportion of mining households. The PSM model used in this study to analyse the impact on poverty of the four

Table.2 Demographic and socio-economic data of the sample villages

Item	Ok Tedi mining	Ok Tedi non-mining	Porgera mining	Porgera non-mining
Demographic information (mean)				
Age	43.68	43.83	46.22	42.13
Gender (M=0, F=1)	0.16	0.10	0.28	0.26
Employment (frequency)				
Unemployed	53	78	59	80
Employed	100	71	97	71
0=no grade completed	36	55	35	90
Education (frequency)				
1–12=school years	36	74	50	44
13=trade certificate	48	8	50	2
14=other certificate	20	5	14	10
15=diploma	12	6	4	2
16=degree	1	1	3	3
17=postgraduate	0	0	0	0
Productive adults per household (frequency)				
1	10	10	7	10
2	66	86	96	69
3	31	26	37	36
4	30	21	11	18
5	3	2	2	6
6	7	0	2	4
7	2	1	0	3
8	3	1	1	3
9	0	1	0	2
Food security & quality (mean)				
Food eaten in the last 30 days (1=often not enough, 4=enough and the kind we prefer)	3.20	2.12	2.85	1.67
3 square meals last 12 months (1=never, 5=always)	4.09	2.74	3.64	1.69
Income satisfaction (1=insufficient to 4=more than enough)				
Income satisfaction (mean)	1.66	2.60	1.11	2.64
Life satisfaction: rich–poor ladder (frequency)				
Step 1	0	5	4	67
Step 2	2	38	17	62
Step 3	4	65	28	19
Step 4	20	27	22	1
Step 5	83	7	68	2
Step 6	23	5	15	0
Step 7	9	2	2	0
Step 8	9	0	0	0
Step 9	3	0	0	0

categories of factors is shown in Fig. 2. For example, education and education grants are usually available to mining households but not to non-mining households. This model used the measurement variables shown in Table 1.

In the binary logistic regression model, there were two cases: mining households and non-mining households. Denoting the binary treatment condition as W_i ($W_i = 1$,

if it was a mining household, and $W_i = 0$, if it was a non-mining household) for the i th case ($i = 1, \dots, N$), the vector of conditioning variables as x_i and the vector of regression parameters as β_i , a binary logistic regression that depicts the conditional probability of being a mining household is as follows:

$$P(W_i|X_i = x_i) = E(W_i) = \frac{e^{x_i\beta_i}}{1 + e^{x_i\beta_i}} = \frac{1}{1 + e^{-x_i\beta_i}} \quad (1)$$

In this model, the dependent variable W_i is a non-linear function of the vector of conditioning variables (x_i). However, by using a linking function such as a logit function, the model can be expressed as a generalised linear model (McCullagh & Nelder, 1989). So while W_i is not a linear function of x_i , its transformation through the logit function (i.e. the natural logarithm of odds) or $\log_e \left\{ \frac{P(W_i)}{[1-P(W_i)]} \right\}$ produces a linear function of x_i

$$\log_e \left(\frac{P}{1-P} \right) = x_i\beta_i \quad (2)$$

where P denotes $P(W_i)$. The model estimates the probability of a household being a mining household, given its various attributes, such as economic opportunities, capabilities, security, empowerment and level of poverty.

The second step of the PSM method requires the investigation of the overlap of the propensity scores in the two groups. By comparing the minimum and maximum values of the propensity scores of the mining and non-mining groups, the region of common support is defined. A sufficient region of common support is required for the PSM method to proceed. This rules out the phenomenon of perfect predictability of D given x :

$$(\text{Overlap}) 0 < P(D = 1 | x) < 1 \quad (3)$$

The region of common support guarantees that households with the same x values have a positive probability of being mining households and non-mining households (Heckman et al. 1999).

In the third step of the PSM method, the ATT is estimated. The ATT shows the effects of being in a mining community as measured through the attributes such as economic security. The ATT is estimated by matching pairs of mining and non-mining households that are closest in terms of their propensity scores. The ATT is calculated as follows:

$$\text{ATT} = E(T|D = 1) = E(Y(1)|D = 1) - E(Y(0)|D = 1) \quad (4)$$

where $E(Y(1)|D = 1)$ represents the expected impacts of mining on mining households and $E(Y(0)|D = 1)$ denotes the counterfactual impacts on non-mining households (Shehu and Siddique 2014). The key assumption is that adjusting for pre-treatment differences enables causal effects to be estimated in an unbiased manner.

There is a final issue that needs to be considered in the PSM method. Because $p(X)$ is a continuous variable, the probability of observing one mining household and one non-mining household with the same propensity score is actually zero. This means that a system must be devised to match mining and non-mining households that have similar

Table 3 Results of the logistic model based on combined Ok Tedi and Porgera data: dependent variable probability of being a mining household

Mining and non-mining	Coef	$P > z$	95% Conf	Interval
Inside capital	0.42	0.000***	0.23	0.60
Human capital	1.46	0.000***	0.72	2.21
Food eaten in the last 30 days	2.10	0.000***	1.40	2.79
Square meals in 12 months	1.75	0.000***	1.01	2.40
Income satisfaction	-2.36	0.000***	-3.23	-1.48
Village participation to help	0.55	0.000***	0.27	0.83
Information volunteering	-0.33	0.027**	-0.63	-0.04
Rich-poor ladder	1.05	0.000***	0.75	1.36
Constant	-4.18	0.000	-5.51	-2.85

Number of observations = 604; pseudo- R^2 = 0.676; LR test (χ^2) = 565.97; P value = 0.000; log likelihood = -135.51. Source: XXX (unpublished PhD thesis [name of author is suppressed to preserve the anonymity of the review process])

** Significance level of 5%

*** Significance level of 1%

propensity scores. There are a number of matching techniques suggested in the literature, with the most used being nearest neighbour matching, radius matching, kernel matching and stratification matching (Becker and Ichino 2002). We present results for radius and kernel matching methods. Radius matching uses all of the non-treated comparison observations within a pre-determined radius (Shehu and Siddique 2014). The advantage for radius matching method is that it uses all the comparison units that are available within the radius. Kernel matching matches all treated units with a similar weighted average to controls (Li 2013).

Results and discussions

The logistic regression results are shown in Table 3. These datasets from Ok Tedi and Porgera were combined for this analysis. The explanatory variables (human capital, inside capital, village participation to help, information volunteering, food eaten in the last 30 days, square meals in 12 months, income satisfaction and rich and poor ladder) are all significant at least at a 5% level, showing that these variables are indicators of whether a household is from a mining village. The LR test (χ^2) is significant, and with a pseudo- R^2 value of 0.68, the model has reasonable explanatory power

Fig. 4 Relationship between index of human capital and probability of being a mining household.

Source: XXX (unpublished PhD thesis [name of author is suppressed to preserve the anonymity of the review process])

for this type of analysis. Similar results were obtained for Ok Tedi and Porgera regions separately (see XXX).¹

Inside capital (related to economic opportunities) includes televisions, VCD/DVD players, refrigerators, freezers and cars. As expected, inside capital is directly related to the probability of being a mining household (see Table 3). The mining villagers accumulate inside capital based on their increased income.

Human capital (related to capabilities) measures the education level of the households. Again, this has a positive and significant coefficient (see Table 3), suggesting that human capital directly affects the probability of an observation being from a mining household (see Fig. 4). This is likely to be a result of more school places being available in mining villages, and mining households having more discretionary income to support children at schools and university.

Security is the third aspect of the mining–poverty reduction linkage approach. This was assessed using the three variables: food security, food quality and income satisfaction. The results show a direct relationship between the probability of an observation being from a mining household and both food eaten in 30 days (quantity) and the number of three square meals per day over 12 months (quality). Hence, more food is eaten per person in the mining villages.

Income security was measured as income satisfaction: the level of satisfaction gained from a given level of income. The logistic model results show an inverse relationship between income satisfaction and the probability of a household being from a mining community. Therefore, a typical non-mining household obtains a higher level of satisfaction for a given level of income than a typical mining household.

There may be several reasons for this. First, the availability of more items to purchase could induce a higher level of demand. Hence, even though mining households may have more income on average than non-mining households, it may not be enough to satisfy their expanded wants. Second, it typically costs more to live in mining communities which are part of the modern economy. In contrast, non-mining households typically continue to live in an agrarian system that operates without money for many transactions. Gardens can provide free food, free water can be obtained from the creeks and the community constructs houses with free labour. Hence, it is not surprising that a given amount of money income provides a higher level of satisfaction for non-mining households.

Social assets (as aspects of empowerment) were also expected to differ between mining and non-mining households. The safety net “Wantok system” is well known in PNG. As discussed above, social assets were analysed using the variables village participation to help and information volunteering. Village participation to help is a measure of the extent to which villagers participate to help each other, and is an important part of the social safety net. The results show a direct relationship between the probability of an observation being from a mining household and village participation to help. As noted above, this may partly be related to the efforts of mining companies providing support services in mining villages through the community relations office.

A second aspect of social capital is information volunteering. It consists of speaking to the media about an issue or problem, involvement in an information campaign and volunteering to help in the community. In PNG, these activities are important in informing and hence empowering households about potential impacts on their livelihoods. In the mining communities, sharing information with households

¹ Unpublished PhD thesis (name of author is suppressed to preserve the anonymity of the review process).

Fig. 5 Relationship between position on the rich–poor ladder and probability of being a mining household.

Source: XXX (unpublished PhD thesis [name of author is suppressed to preserve the anonymity of the review process])

is central to empowered decision making. This can enable the indigenous people to take informed action in face of the announced changes. Local people enjoy the social aspects of volunteering, especially for church and community organisations. Also, there would be more influence of the group in the community when there is more people interacting. In the logistic model estimation, an inverse relationship was observed between information volunteering and the probability of an observation being from a mining household. This indicates that there is more information volunteering in non-mining households.

A household's overall perception of wellbeing was measured using the rich–poor ladder. Households were asked during the survey questionnaire to estimate their own position on a particular rung of the ladder. The results indicate that the position on the rich–poor ladder was directly related to the probability of a household being from a mining village. Hence, there are more mining households higher up the rich–poor ladder (see Fig. 5).

A wide region of common support was discovered at the second stage of the PSM analysis. This was the basis of progressing to the third stage of propensity score matching, estimating the ATT. By comparison with non-mining households, this shows the impact of mining on the mining households. Here, we focus on the 9-point scale of the rich–poor ladder as the overall index of poverty (see XXX for more detailed results).² Table 4 contains the results. We

show progressive results for a dummy variable regression, a regression extending this dummy variable model to include other explanatory variables, and then the two ATT results for kernel matching and radius matching, respectively. A difference is observed between mining and non-mining households of 2.234 (on a 9-point scale) in the mean value

Table 4 Average treatment effects on the treated (ATT) for radius and kernel matching methods (performance index: rich–poor ladder)

	ATT	t
Model 1: combined OK Tedi and Porgera mining		
Radius	0.890***	5.365
Kernel	0.138	0.431
Regression	1.055***	6.840
Dummy variable regression	2.324***	22.100
Model 2: regional OK Tedi mining		
Radius	0.862**	2.384
Kernel	1.184**	2.623
Regression	1.427***	5.290
Dummy variable regression	2.193***	16.170
Model 3: regional Porgera mining		
Radius	1.561**	2.352
Kernel	−0.703	0.549
Regression	1.819***	3.120
Dummy variable regression	2.457***	19.550

Source: based on XXX (unpublished PhD thesis [name of author is suppressed to preserve the anonymity of the review process])

**Significance level of 5%

***Significance level of 1%

² Unpublished PhD thesis (name of author is suppressed to preserve the anonymity of the review process).

on the rich–poor ladder when there are no other explanatory variables apart from the mining/non-mining dummy. This is reduced to 1.055 by the inclusion of the other explanatory variables. Next, by estimating the ATT, these values are adjusted further for the non-random effect of households being in mining villages. The ATT estimates range between 0.138 (and insignificant) and 0.890 (and significant) for the two matching methods. Hence for the combined Ok Tedi and Porgera dataset, once the bias of non-random effects has been removed, mining is shown to have had an unconvincingly positive impact on the rich–poor ladder index of poverty. Moreover, relative to the 9-point scale, the impact could be considered small.

Also shown in Table 4 are results for the two regions separately. At Ok Tedi, the ATT ranges from 0.862 to 1.184 for the two matching methods, and both are significant. These results provide some confidence that there has been a positive impact of mining on the perceived levels of poverty at Ok Tedi, but again, they are small values on a 9-point scale. The ATT results for Porgera are statistically significant only for radius matching, with an increase in the mean position on the rich–poor ladder for mining households of 1.561 units. These results at the regional level tend to confirm the results from the dataset from both regions combined that there is a small and unconvincing positive impact of mining on poverty.

Conclusions

Mining in Papua New Guinea has often been associated with adverse environmental, social and economic outcomes for the indigenous peoples. From this background, we set out to estimate the impact of mining on indigenous communities in two significant mining locations at Ok Tedi and Porgera. Various indicators of poverty were employed within the sustainable livelihood framework. Extended into a mining–poverty reduction linkage approach, the SLF provided the theoretical foundation for the study. This foundation supported the use of the propensity score matching method by focusing on economic opportunities, capabilities, security and empowerment, as drivers reducing poverty.

Our results indicate that at Ok Tedi and Porgera mining has reduced poverty when measured using the variables human capital, inside capital, village participation to help, food eaten in the last 30 days and square meals in 12 months. There is more income for the mining households as indicated particularly by an increase in investment in human capital, but the food quality and security of food supply have also improved. However, there is less information sharing compared to non-mining households. Also, crucial ATT estimates from the propensity score matching indicate only a small and unconvincing impact of mining on poverty, as

measured by mean position on the rich–poor ladder. In other words, even though there has been improvement in the key drivers of the sustainable livelihood framework: economic opportunities, capabilities, security and (partly) empowerment, the indigenous peoples affected by mining consider that they have experienced only a small positive impact from mining.

With respect to methods, propensity score matching was employed to correct for the non-randomness in the selection process of alternative methods. This was seen to be essential because the results are different from methods that do not correct for this bias. In the analysis presented, propensity score matching produces smaller coefficient estimates for the impact of mining on the rich–poor ladder (and for most of the other key variables measuring opportunities in relation to poverty) that are less significant than for methods that do not apply the correction. Hence, the correction to overcome non-randomness bias using propensity score matching was warranted.

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Author contribution Londari Yamarak and Kevin Parton: conceptualisation, methodology, data analysis, writing of the original draft and writing which includes review and editing.

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Data availability The data are available from Dr. Yamarak.

Declarations

Ethics approval The project was approved by the Charles Sturt Human Research Ethics Committee.

Conflict of interest The authors declare no competing interests.

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