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Innovation for sustainable development in artisanal mining: Advances in a cluster of opal mining in Brazil

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ABSTRACT

The objective of this article is to understand how the promotion of clusters of small economic agents in the gem sector has brought some improvements in the economic, social and environmental conditions in the mining sector and activities related to it. The research provides policy and theoretical contributions to the field of gem production, as well as enhances understanding of the under researched opal production in Brazil. It argues that government funding and technical support dedicated to the development of mining clusters, i.e. working with small economic agents as a whole and not individually, could promote not only more economic development, but also effectively incorporate social and environmental issues, such as workers safety, water management and tailings recycling. The argument is based on an evaluation of environmental, economic, social and institutional aspects of the opal mining cluster in Pedro II municipality, Piauí state. The results suggest that some formalisation of existing practices and adequate policies have triggered innovation with some positive effects on the performance of artisanal mining. Nevertheless, there are indications that if decision-makers plan to make this cluster more sustainable, they will have to include other issues in the debate including developing substituting economic activities.

Introduction

In various developing countries, artisanal mining has been proposed as a viable strategy to promote local development (Puppim de Oliveira and Ali, 2011); Siegel and Veiga, 2009). Despite its positive economic aspects artisanal mining might also create some negative social and environmental consequences, such as unsafe working conditions, deforestation and water pollution. This article analyses, from both policy and theoretical perspective, to what extent the idea of clusters can be a feasible strategy to strengthen positive effects and mitigate negative impacts of artisanal mining related activities.

From the practical perspective, this article provides policy understanding on how to improve gem mining, particularly in Brazil and other developing countries, as it is mostly performed by garimpeiros (small artisanal miners) and small companies, to a large extent working informally. The International Labour Organization (ILO) estimated more than 13 million artisanal miners working around the world in the beginning of the 2000s, the majority in developing countries (Hinton et al., 2003; Veiga, 2001). Although these activities create economic benefits, they might also result in social and environmental negative impacts due to unclear rules and inefficient technologies, which create risk to the workers, the neighbour communities, as well as, to the local environment.

Additionally, from the conceptual point of view, the article attempts to create a dialogue between the literature on Small and Medium Enterprises (SMEs) clusters (Amorim, 1998; Schmitz and Nadvi, 1999; Lastres et al., 2005; Puppim de Oliveira, 2008) and artisanal mining. In this sense, it is an effort to identify to what extent clusters could not only facilitate the promotion of technological development in artisanal mining but also increase social and environmental benefits of the mining activity, and consequently reduce its stigma as a degrading economic activity. Therefore, this article brings some reflection on a new front concerning gem small scale mining (Puppim de Oliveira and Ali, 2011).

In order to collect empirical information to base these arguments, a case study in opal mining was developed in Piaui, Brazil. The research is based on the case study methodology (Yin, 1994) with documental and data collection together with in-depth field research including semi-structured interviews (Weiss, 1995) and oral transcribed interviews (Oishi, 2002). The interviews included *garimpeiros*, gem dealers, jewellers, and representatives of institutions that support the cluster.

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The article is divided as follows. It presents a conceptual debate on potential advantages of clustering policies as driving forces for moving artisanal mining towards innovation and better social and environmental performance. Then, some characteristics of gem mining in Brazil is presented. The case of opals in Pedro II section describes the opal mining cluster in Pedro II; this description includes a few economic indicators of Pedro II region, some opal general characteristics, and the main activities developed in the cluster. Afterwards, it is evaluated to what extent innovation adopted in the opal cluster has affected its economical, social and environmental performance. In the last section, the main conclusions are summarised.

Innovation and the environment in clusters of artisanal mining

Artisanal and small-scale mining has been proposed as a strategy for local economic development due to its labour intensity and potential capacity for creating jobs, often in remote regions where there are not many other economic opportunities. However, artisanal mining, when done informally, has also been criticised for its socio-environmental impacts, including atmospheric and water pollution, land degradation and deforestation, as well as, conflicts over land use. As a result, there is a growing demand for the development of more sustainable practices within this sector (Ali, 2003; Amankwah and Anim-Sackey, 2003; Hilson, 2003), which means not only enhancing short-term economic results, but also improving social and environmental performance, as well as strengthening post-extractive economic activities. Along these lines, the main objective of this article is to understand to what extent cluster policies in small mining could not only stimulate local economic development, but also encourage artisanal miners in adopting managerial and technological innovation that can help protecting the environment and miners as well as generate more local economic development. In bringing this debate to the context of artisanal mining, it is expected to contribute to the design of strategies that help artisanal miners in developing countries to change their current situation and adopt practices that include safe working conditions, environmental protection and respect to tax and labour legislation.

The debate concerning clustering policies in artisanal mining is still recent; then, most of the theoretical arguments presented have been "borrowed" from the literature on SMEs. Although artisanal mining and SMEs have several different features, it is argued that, in developing countries, they share various common aspects, such as high level of informality, restricted access to technical expertise and limited financial resources. Therefore, it is argued that some strategies and policies developed to support clusters of SMEs could also be used in the implementation of clusters of artisanal mining.

The literature on socio-environmental performance in SMEs, argue that these companies, usually present poor levels of socio-environmental initiatives (del Brío and Junquera, 2003). This scenario derives from various barriers to the implementation of good practices, such as lack of resources and information, uncertainty regarding potential benefits, interruptible implementation processes, inconsistent support, cultural scepticism, insufficient economic drivers, and unclear legislative framework (Hillary, 2004). These findings seem to be consistent with research developed in Brazil. There, SMEs do not have enough financial capacity to invest in preventative innovations and usually choose corrective actions, which, sometimes, only increase operational costs. For example, according to a national survey, considering a sample of more than 41,000 companies, 68% declared that innovation had little or no effect on the company environmental impacts (IBGE, 2010). Within this context, Brazilian SMEs seem also to suffer from lack of information and a general resistance to adopt socio-environmental management practices, which make adoption of those initiatives even more atypical (Jabbour, 2011). Here, it is argued, that similar aspects can be identified among artisanal mining.

The development of cluster in SMEs and artisanal mines could be a strategy to overcome some of these limitations. Clusters may be defined as a geographic concentration of interconnected economic agents (firms and individuals) in the same economic sector, including suppliers, service providers, and supporting organisations, such as local governments and business associations (Puppim de Oliveira and Ali, 2011). The locational aspect is a key aspect in creating new informational, transaction or incentive efficiencies (Porter, 2000), as well as, promoting economies of scales and scope (Walker and Minnitt, 2006).

It is assumed that a study on clusters must consider agents which are internal and external to the cluster, in a way that it allows a broad understanding of economic, social and political characteristics of the production chain (Ipiranga et al., 2007). Clusters also signifies more than physical proximity, but can also be understood by some common social and political aspects, such as continuous and repetitive interactions among agents, formal and informal networks, social incentives to entrepreneurship and a sense of belonging to the cluster (Ipiranga, 2008).

Therefore, a cluster can be a useful conceptual model to evaluate artisanal mining. It is not uncommon that clusters are naturally developed in mining regions because, as mineral deposits are geographically determined, economic agents have to move towards the mineral sources and end up developing similar and related economic activities in the region. In other words, minerals attract mining activities, which bring miners, mining companies, training organisations, unions, equipment maintenance firms, jewellers and traders, among others (Puppim de Oliveira and Ali, 2011). In this sense, even in the case of mining, the constitution of local clusters can create the basis for leveraging long-term and sustained economic diversification and development (Walker and Minnitt, 2006). Nevertheless, it is necessary to understand how to induce the implementation of mining projects that do not focus only on short-term economic results, but also adopt initiatives that consider long-term economic, social and environmental benefits.

There is a broad literature on clusters, which is not only descriptive, but also proposes policies and tools to enhance cluster implementation and development (Altemburg and Meyer-Stammer, 1999; Schmitz, 1995; Schmitz and Nadvi, 1999). Most of these studies focus on issues such as productivity, competitiveness, technology development and innovation (Silva and Demajorovic, 2008; Walker and Minnitt, 2006). Among these topics, technology development and innovation are strategic issues, as they are seen as means to increase productivity and competitiveness. Literature usually defines innovation as "a new or significantly improved product (good or service) introduced to the market as well as new or significantly improved process introduced within the enterprise" (Radas and Božić, 2009, p. 438). In other words, innovation, in a broad sense, is considered either usual ways of doing new things, or new ways of doing usual things.

Studies on SMEs' capacity to innovate identify a general limitation regarding resources and capabilities, including problems of research and development activities, as well as, personnel education and training (Massa and Testa, 2008). Such limitations can be also associated to artisanal mining. On the other hand, clusters are perceived as feasible schemes to overcome such limitations as they create collective institutions such as networks of social relations (Coenen and Díaz López, 2010), exposition to richer insights and service concepts (Porter, 2000) and links with other companies and research institutions (Radas and Božić, 2009).

Although part of the literature looks at innovation in general, there are authors who debate linkages between technology and

socio-environmental performance. In this realm, environmental technology is usually defined within four categories: measuring techniques, end-of-pipe approaches, cleaner technologies or zero impact solutions (Kuehr, 2007). SMEs in developing countries, as well as, artisanal miners, hardly ever adopt any of these solutions, and it is argued that policies towards environmental technologies should not be restricted to end-of-pipe solutions, but also prescribe transition strategies to include preventative and zero-impact practices. Such policies seem to be consistent with the literature, once it proposes potential synergies between innovation and better environmental performance. Moreover, authors argue that new technologies could simultaneously reduce environmental impacts and increase company competitiveness (Mol, 1996; Young, 2000). This line of argument is based on the assumption that technological innovation would increase efficiency, not only reducing production cost, but also diminishing pollution and natural resource depletion. Other possible contribution could be the development of preventative solutions, which could avoid some environmental impacts and reduce costs related to corrective actions (Cohen, 1997; Rinkevicius, 2000).

Looking specifically at small mining, it has been proposed that formalisation should also be considered a priority to the sector. It is argued that issuing formal property titles attaches miners to the land, discouraging transient, inefficient, ecologically harmful mining, and increasing concerns with the local environment and the use of proper mining techniques. Additionally, it ensures rights to minerals and capital, making micro-loans and investment in technology possible (Siegel and Veiga, 2009). Here, it is argued that cluster policies could also stimulate formalisation.

Nevertheless, clusters should not be seen as a panacea to all the problems faced by SMEs or artisanal mining. The development of a cluster depends on more than good public policies (i.e. government plans, programmes and initiatives), and they also have to face obstacles. The literature mentions some cultural difficulties, particularly related to cooperation among firms; the lack of intermediate organisations that create links between government and firms; and infrastructure beyond the cluster area of influence (Vonortas, 2002).

Despite these limitations, it is argued that the promotion of clusters could be considered a strategy to develop managerial arrangements and mining technologies that improve material efficiency and increase mine life expectancy. When bringing these issues to the clusters' agenda it is important to consider that these arrangements have solid technical and social bases on their territory (Goulart, 2006), being a feasible strategy to turn artisanal mines into long-term projects. In spite of these advantages, there is little research about how clusters improve economic, social and environmental performance in developing countries (Silva and Demajorovic, 2008).

In order to promote advances in mining, this article proposes to evaluate to what extent could policies developed to strengthen clusters through their opportunities of taking advantage of the economies of scale or collective efficiency, improve environmental and social conditions (Puppim de Oliveira, 2008). Along these lines, many mining clusters could create the conditions to improve social and environmental performance, as compare to dealing with individual miners or companies, such as:

- Increasing scale and level of formalisation;
- Enhancing information diffusion and learning through the interaction with different stakeholders and promoting technological innovation;
- Accessing and developing expertise through interaction with cluster supporting agencies and external consultants;
- Reducing individual costs of environment control technologies, as miners or companies could find collective solutions or increase the scale of markets for individual equipments;
- Diversifying the economy, and stimulating other economic sectors.

These opportunities indicate the need of in-depth studies concerning aspects of clusters and artisanal mining. This article attempts to identify the debates on some of these issues, based on the experience of the opal mining cluster in Pedro II.

Background: gem prospecting in Brazil and Piauí

Overview of artisanal gem mining in Brazil

There are no updated official data about *garimpeiros* and small mining in Brazil. In 1993, the National Department of Mineral Production (DNPM) completed a National Survey on Small Mining and estimated some 400,000 *garimpeiros* and 2000 small mines nationwide. On the other hand, more recent information refers to 18,000 *garimpeiros* working in cooperatives, but does not mention informal mining (DNPM, 2008). The lack of reliable data concerning artisanal mining is one of the main obstacles to policies towards the sector. Nevertheless, in artisanal mines, the work is mainly performed by non-qualified labourers (Miranda et al., 1997), who are commonly hired by oral contracts (Barreto, 2001).

In order to organise and formalise the work of the *garimpeiros*, the Federal Government passed the Small Mining Permission Act (1989) in 1989. This act made it possible to small miners to formally mine an area without previous mineral/geological research (an obligation for large scale mining, according to Brazilian legislation). Although a Small Mining Permission still requires an environmental consent, in principle, it is easier to obtain than the usual mining permission. The act still requires *garimpeiros* to be organised, preferably, in cooperatives. According to the act, a small mine cannot occupy an area larger than 50 ha, unless it is required by a cooperative, when it can have up to 1000 ha, reaching 10,000 ha in the Amazon region (DNPM, 2007a).

The main objective of this Act was to stimulate the creation of *garimpeiros'* cooperatives and to reduce the level of informality in small mining. However, experience shows that, in various situations, the creation of cooperatives is a mere bureaucratic act, which has no impact on the customary working relations, as within the same cooperatives some members hire others to mine for them (Teixeira and Lima, 2004).

Informality is particularly high in the gem mining, for several reasons. Firstly, gems can be often extracted without modern technology or highly qualified labour, being accessible to artisanal operators, particularly when they are found in the surface. Secondly, gem mining is a high risk activity because of the uncertainties in finding good quality gems, even with good geological research, discouraging the involvement of large firms. Finally, government agencies generally lack sufficient qualified staff and infrastructure to control dispersed and varied artisanal gem mining, thus it is not given enforcement priority.

Besides economic informality, other typical problem of artisanal mining in Brazil is the limited access to proper machinery. Thus, activities are usually performed manually or with rustic equipment (Macedo et al., 2003). As a consequence, artisanal mining is characterised by its physical risks and low productivity, impacting the *garimpeiros'* returns for their labour efforts.

Other particularity of artisanal mining of gems is the kind of environmental impact it creates. This activity does not use chemicals and, often, is restricted to small areas. In principle, these characteristics would make mitigation and remediation of environmental impacts simpler. However, the aggregated effect of many mines in the same region on the environment is considerable. The most common impacts are deforestation, water pollution

and river siltation. In addition, potholes, ditches and tunnels considerably change the landscape. Although these impacts could be easily corrected, historically, *garimpeiros* have not taken action to prevent or mitigate (Macedo et al., 2003). Moreover, as the impacts of gem mining are considered less serious as compared to other kinds of artisanal mining (such as gold), they are usually overlooked by environmental agencies.

Mining in the Piauí state

Piauí, located in the Northeast region, is one of the poorest states in Brazil. In this region, artisanal mining is carried out in an even more precarious situation than in the rest of the country. Only 40% of the small mines have some sort of machines, such as trucks and bulldozers (Fundação CEPRO, 2005). There are water pumps in a few mines, but as the mines generally are not connected to the electric power grid, *garimpeiros* use oil engines, which increase operational costs and environmental pollution.

Gem prospecting is a common practice in many parts of the Northeast Region, particularly during the dry season, as a complement to agricultural work (the Northeast region is characterised by a semi-arid climate, and agriculture only happens during the short raining season). This balance between small mining and subsistence agriculture is an important strategy to sustain local economy in areas where gems can be found (Sicsú and Lima, 1991). According to official data, in 2008, gem mining in Piauí generated revenue of €95,940, and opal mining in Pedro II was responsible for 29% of this revenue (DNPM, 2013).

In spite of its quantitative importance, the actual contribution of artisanal mining to local economies must be considered cautiously. Although there is no current official data regarding *garimpeiros'* income, Miranda et al. (1997) mention that, in 1993 their national average income (assuming 60 h of work per week) was equivalent to 0.62 oz of gold per month (€427, values of 2008); while in the Northeast region, the average was equivalent to 0.29 oz of gold per month (€199, values of 2008). Despite the low income, people work as *garimpeiros* in average for 13 years in Piauí state, while the national average is only four years.

In Piauí, gem mining, and the mineral sector as a whole, faces many obstacles. The most commonly mentioned in the literature are lack of technical support, including geological surveys and laboratories for mineral analysis, precarious infrastructure (e.g., transport, energy, communication) and limited institutional capacity of government agencies (Fundação CEPRO, 2005). Despite these limitations, the best opal pockets in the country are found in Piauí, and where the opal cluster has developed.

The case of opals in Pedro II

Pedro II

Pedro II is located at the northwest of Piauí state, 200 km from Teresina, the state capital. The urban centre is at the *Serra dos Matões* (Matões Range) 600 m above the sea level. Because of the elevation and the arid climate, the town has mild temperatures, being locally known as the "Switzerland of Piauí".

This is a small town, with a mostly rural economy. In 2010, there were around 37 thousand inhabitants, 40% of which lived in the rural area; this percentage was higher than the state average (34.2%) and the national average (15.6%). The local infrastructure is very precarious; for example, only 54% of urban households had access to treated water in 2010 (IBGE, 2013).

Social conditions in Pedro II are also poor; the per capita income was half of the state average and a fifth of national average in 2000; additionally, 75% of the population earns half of the national minimum wage. Considering the Human Development Index (HDI), Pedro II is far below the national average, being among the 20% least developed municipalities in the country (UNDP, 2003). According to staff from local government, between 2004 and 2007, the number of families that received cash transfers from Federal Government Programmes increased from 1800 to 7000 (Martins, 2007).

The economy of Pedro II heavily depends on agriculture and ranching, but this semi-arid region is subjected to regular droughts, and rain is unreliable. Moreover, underground water is very scarce (Oliveira and Cardoso, 1979). For example, in 2005, farmers had heavy losses in their harvest of rice (85%), corn (75%), beans (56%) and manioc (48%) because of droughts (Batista, 2005).

Opal mining and jewellery has had a fluctuating importance in the local economy since 1940s. Nowadays, collective initiatives have been taken by private actors as well as local, state and federal governments in order to strengthen the opal cluster. These initiatives have increased opal exploitation, polishing, jewel-making and mining-related tourism. Other activities like handicraft have also been promoted. In 2005, the National Agency for Supporting Small Businesses (SEBRAE) supported the creation of the Pedro II Craftsmen Association, which produces hammocks and other weaving products (Jansen, 2005).

Opals in Pedro II: a brief history

Opals[2] have been used in jewellery since 400 B.C. and their value depends on size, colour and colour effects. They can be used in jewellery and handicrafts. Australia is responsible for around 90% of opal production in the world, being followed by Brazil, Mexico, United States and Honduras (Oliveira, 1998;Watkins et al., 2009). In Brazil, opals have been found in various states, including Minas Gerais, Bahia, Mato Grosso, Rio Grande do Sul, Paraná and Ceará. However, the most important reserves are in Pedro II municipality (Fundação CEPRO, 2005; Oliveira and Cardoso, 1979).

The discovery of opals in Pedro II is not documented, being only narrated in *garimpeiros'* oral history. There are different versions about the finding of the first opal. It is consensual that the first gem was found at the end of 1930s, when mining and prospecting started to take place. Many gems were found in an area known as "Crispim", still the main deposit in Pedro II.

In the mid-1960s, a company—Empresa de Minérios Brasil Norte-Nordeste (EMIBRA)—started exploiting the Boi Morto mine in Crispim area. Reports indicated reserves of, approximately, 30,000 kg, in an area of 355 ha. Between 1960 and 1976, the company had more than 80 miners working in the area. During the opal "gold age", there were more than 30 mines in Pedro II. Companies exploited the larger primary deposits, while *garimpeiros* worked on secondary deposits along riverbeds. Nevertheless, most opal was traded in the informal market and there are no reliable statistics about production. The Brazilian Mining Annual Report (a publication by the Ministry of Mining and Energy) did not have production figures, and exports summed only one to six kilograms per year in that period (Oliveira and Cardoso, 1979).

However, in the early 1980s, many companies fled Pedro II and output decreased. An important aspect related to the output decline was the closing down of EMIBRA and the Boi Morto mine. In that period, Oliveira and Soares Filho (1983) found 22 abandoned mines, and only three still active. The authors comment that they identified more than 200 *garimpeiros* in town, but only 30 worked exclusively in mines. After mid-1980s, *garimpeiros*, and

[2] Although traded as gem, the opal is an amorphous combination of silica and water, impregnated with impurities, such as calcium, magnesium, aluminium oxide, or iron oxide (Souza, 1985).

not mining companies, were the main source of opals. In 1988, *garimpeiros* occupied the Boi Morto mine; they scavenged the tailings and, sometimes, tried their luck in the galleries; yet, their activities were not supervised, and landslides became common (Souza, 1985). At that period, the local office of the Secretariat of Federal Revenue Department[3] was shut down, suggesting a significant reduction in the mining activities (Oliveira, 1998).

The most probable explanation for these trends was an increasing difficulty in finding high value opals. Nevertheless, it is not clear if such a reduction was a result of the natural exhaustion of the reserves, or of inadequate exploration. Studies calculated a total reserve of 1,200 metric tons of opals in Pedro II (Oliveira, 1998), however, it is very difficult to know how much still lies in the underground as there is no comprehensive recent study.

The development of the opal mining cluster

In the late 1980s, some private and public agencies tried to revitalise the opal sector in Pedro II. The main strategy was training local people in jewellery to add value to the raw opals extracted in the region, increasing the number of people working in the sector and the local income. In 1988, the Piauí State Development Company (COMDEPI) offered courses for opal cutters. As a result, it was created the first school of mineral handicraft in Pedro II; however, the school was moved to a larger town a few years later (Oliveira, 1998).

In spite of policy discontinuity, the project produced results and a few workshops and jewel shops were opened in the city. After the end of COMDEPI school, some entrepreneurs travelled to Pirenópolis in the state of Goiás (one of the main gem cutting centres in Brazil) to hire jewellers to work and teach jewellery in Pedro II. As the local market for cut stones and jewels increased in Pedro II, some *garimpeiros* also opened small workshops and jewel shops.

In spite of these initiatives, the first studies about the opal production chain in Pedro II identified, at every stage, very low technological and economic efficiency (FINEP, 2005). From the technological perspective, this condition created inadequate labour conditions, environmental problems, inefficient mining process and low value products. Initiatives related to the *garimpeiros'* labour rights have been adopted before the Opal Cluster Project. In 2001, SEBRAE technically supported a group of *garimpeiros* in creating an association to coordinate the activities. However, after this process, DNPM informed they had to create a cooperative, in order to obtain the mining rights. As a result, they finished the association and created a cooperative in 2004.

In the early 2000s, mining-related activities increased in Pedro II, because an Australian company intended to resume mining at the Boi Morto mine. Initially there were conflicts between the company and the *garimpeiros* that worked in the debris from previous mining efforts in the area; this dispute between an international company (which had the legal rights over the mine) and local people (who mined in the debris of the old mine for subsistence but were illegally occupying the area) created certain uneasiness in town.

In 2003, this conflict called the attention of the local press and governmental agencies (such as the Federal and State Environmental agencies, IBAMA and SEMAR, DNPM and the Public Prosecutor's Office). As a result, agencies decided to close the Boi Morto mine, as well as other mines in the region, because none of them had environmental or mining permits (Landim, 2007). This situation, however, could not be sustained for a long time, as *garimpeiros'* income depended heavily on mining activities, and they were important for the town's economy (CETEM, 2005). As a result, the parts negotiated and the company yielded the area of the tailings of previous large scale mine (but still with large amounts of opal mixed in it) to *garimpeiros*, who agreed in not occupying the galleries anymore and in reforesting the area. In return, the company got the environmental permit to reopen the Boi Morto mine. This solution, however, was only reached after long negotiation, which was mediated by public agencies.

Other outcome of this process was an increasing partnership involving the company, *garimpeiros* and public agencies, which set the bases of the Opal Cluster Project. This project was coordinated by the Piauí State Research Supporting Agency (FUNDAPI) and SEBRAE, and was financed by Research and Project Financing (FINEP), a federal agency linked to the Ministry of Science and Technology. The Project was proposed as an initiative to mitigate some of the problems related to opal extraction in Pedro II. On the *garimpeiros'* side, the main concerns involved obtaining environmental and mining permits, improving working conditions and increasing productivity. From the jewellers' perspective, the project aimed at developing new products, increasing added value and expanding the market (Gomes, 2007).

In spite of the efforts and strategies developed by the Opal Cluster Project, it did not reach a great number of *garimpeiros*. Estimates suggest 300 persons working exclusively in mineral-related activities in Pedro II, and another 400 mining eventually, mainly during the dry season (Garimpeiros têm licença para extrair opala, 2005). Nevertheless, the cooperative has only 70 members, out of which 60 work full time in different mines (Sobrinho, 2007). Mistrust and high enrolment cost are the main obstacles to increase the number of cooperative members (Moraes, 2007). In order to be accepted in the cooperative, a *garimpeiro* has to buy a share, which was equivalent to €135 in 2008[4]; besides that, cooperative members have pay 10–20% of their income from gem sales as overhead costs (COOGP, 2004).

Regarding working conditions, one of the main contributions of the Opal Cluster Project was the improvement of safety (the project hired a mining engineer, responsible for planning new embankments) and ergonomic aspects of *garimpeiros* work. Despite the improvements in the mines, working conditions are still precarious.[5] Aspects that seemed to continue most harmful were the constant exposition to sun, heat and dust, in addition to constant physical effort in digging and transporting the rocks. There is a shed, where *garimpeiros* eat and rest, but it still lacks facilities, such as sinks and toilets.

Moreover, it seems that there was little change in the mine productivity. According to *garimpeiros*, the price of one gram of high quality opal can vary between €34 and €67 in the mine, but they are very hard to find. The project does not keep records of opals according to their different qualities (white, black, fire etc.), but classify them as first class (7% of sales), second class (18%) and third class (75%) (AJOLP, 2007). However, most commonly, *garimpeiros* live off selling *xibiu* (small fragments of opal extracted from mining tailings), and earn around €27 per small batches of 20 ml (Pinto, 2007).

Although working conditions are not ideal in the mines, improvements are more remarkable on the legal front. *Garimpeiros* have always worked informally, without mining and environmental permits. In order to have access to the mines, traditionally, they

[3] The Secretariat of Federal Revenue is a federal agency responsible for exercising tax administration and customs control.

[4] Money values have been converted from Brazilian Reais to Euros, based on the official exchange rate of 01/12/2008.

[5] Mining operations can be divided in four stages. First, there is manual digging; as explosives are forbidden *garimpeiros* must use shovels and pickaxes to extract the soil. Then the material is moved with wheelbarrows to manual sieves, where sand and clay are removed. Finally, the stones are washed in large water tanks, where *garimpeiros* look for opal gems (Pinto, 2007).

make arrangements with the land owner, paying between 15% and 20% of their income. This type of deal has been in place for more than 40 years, as public agencies lacked institutional capacity to monitor the mine activities. The Opal Cluster Project had to face the challenge of changing these arrangements.

From the *garimpeiros'* point of view, obtaining an environmental permit has never been considered because of the high costs involved. In order to obtain the permit, miners have to pay the licensing fees, the studies of environmental impact assessment and the engineers to supervise the works. The Opal Cluster Project hired a mining engineer, who worked as a consultant during the environmental studies and supervised the mining works afterwards, allowing the cooperative to get the environmental permit.

The licensing process also benefited staff from the environmental agencies in Piauí. It has been identified that, before the Opal Cluster Project, they did not know exactly all the procedures related to environmental permits for mining cooperative (Landim, 2007). After the first permit, agencies became more efficient and new permits for cooperatives were issue with time lags shorter than one year (a very good mark for Brazilian standards). As a positive aspect, an increasing efficiency of bureaucratic agencies motivated *garimpeiros* not related to the Opal Cluster to obtain their permits. In 2007, in addition to the three mining permits issued to the Boi Morto mine, there were seven active cooperative mining permits, four prospecting permits, three requests of cooperative mining permits and one request of prospecting permits in the region (DNPM, 2007b).

The Opal Cluster Project has not only supported opal extraction in Pedro II, but also taken action along the production chain. One of its main initiatives has been the creation of the Pedro II Jewellers and Stone Cutters Association (AJOLP). The association was created in 2004, and its main objective is to support jewel production and trading. Individuals and firms who join the association receive training on new processes and financial support to attend jewel fairs and exhibitions. For example, in 2007, AJOLP invited Pedro Brando, a jewel designer from New York, to offer a course in Pedro II. In addition, the association also motivates and supports firms in formalising their business. In this case, the main purpose is getting access to the international market which, in some situations, can represent up to 60% of companies' sales (de Souza, 2007).

In summary, the main advantages of the Opal Cluster Project were improvements in the working conditions, which became safer. From the institutional point of view, *garimpeiros* now work following the mining and environmental legislation, what creates indirect benefits to workers and population in general. Additionally, they are not threatened to be evicted from the mines anymore. However, the cluster still has to face other challenges in the environmental and health conditions.

Discussion

The previous section described the case, pointing out the main characteristics and advances promoted by the Opal Cluster in Pedro II. This section attempts to identify to what extent the Opal Cluster Project had positive impact on the mines economic, social and environmental performance, as well as propose some strategies for improving the situation of the opal mining based in clusters of small production.

Increasing level of formalisation

The Opal Cluster Project had a relevant role in inducing economic formalisation in Pedro II. After the implementation of the project, the *garimpeiros* cooperative and the jewellers association were created, bringing various workers to the formal market, helping to increase tax collection and controlling the impacts of their activities, as well as giving them access to opportunities for improving their businesses.

As far as jewellers are concerned, the association made some improvements possible. For example, increasing access to fairs and helping jewellers in accessing international markets. In addition, the creation of the *garimpeiros* cooperative promoted various relevant positive impacts on the locality. Firstly, the cooperative brought together many *garimpeiros* to work on the Boi Morto site, concentrating their activity and reducing the extension of their environmental impacts. Additionally, the formalisation created positive effects regarding workers safety as well as the environment. On the safety side, the formalisation demanded the work of a mining engineer, which prepared an extracting plan, reducing risks of landslides within the mine. At the same time, the creation of the cooperative made it possible to the *garimpeiros* to apply for the environmental permit to work at the Boi Morto mine. In order to obtain this permit, an environmental impact assessment was necessary, making explicit various impacts and compelling *garimpeiros* in taking corrective actions.

Enhancing information diffusion and learning

Different from the *garimpeiros* cooperative, which concentrates many workers in only one site, the jewellers association is formed by various small workshops. As a consequence, the contribution of the opal project to information diffusion is easier to be noticed among jewellers than among *garimpeiros*.

An important innovation in this field has been the creation of new jewel production techniques using small opal fragments. One of these techniques is the *doublet*, which is an arrangement of a very thin opal layer over another stone glued with an epoxy resin. Alternatively, jewellers also make *triplex*, when a third layer of quartz is added on top of the opal; the *triplex* is particularly effective in making mosaics with very small opal fragments.

Although these techniques have not been created by the Opal Cluster Project, the permanent exchange of experiences among members was important in diffusing them in the region. These new production processes were particularly important in boosting demands for opal fragments and keeping the cluster economically active after the middle 1990s, when good opals were hard to find. Additionally, these techniques also had an environmental contribution, as they made the use of *xibiu* possible. This material is mainly extracted from tailings and its extraction turned old piles of waste into a new source of raw material.

Accessing and developing expertise

As mentioned above, the project has put *garimpeiros* and jewellers in contact with various experts. On the one hand, jewellers have been able to attend training courses given by people from outside Pedro II and even from abroad. On the other hand, the hiring of a mining engineer has been an important contribution to *garimpeiros* as this engineer has developed diverse projects to improve various safety and environmental aspects.

Firstly, there have been advances in minimising water pollution. The Boi Morto mine is located close to a tributary of the Matos River, which is the main water source of many small farms and two towns. In the past, pollution from the mining often reached the local creek, creating problems for irrigation systems. Farmers had to call the environmental agency (IBAMA) to force *garimpeiros* to improve the wastewater management. The mine engineer has guided the *garimpeiros* in building a barrier between the mine and the creek, minimising the problem (Pinto, 2007).

Other important contribution of the project has been putting the *garimpeiros* in contact with the Centre for Mineral Technology (CETEM), a public centre dedicated to mining technology (Peiter and Villas Boas, 2008). The main contribution of CETEM has been the development of an alternative use of the tailings. Traditionally, most of the tailings produced in the Boi Morto mine have been used as backfill, for the lack of other uses. However, CETEM has evaluated the use of this material as building aggregate, and the cluster project intends to build a factory in the region to produce "ecological bricks", which might create new jobs in the region (Werg and Pessoa, 2011).

Reducing individual costs of environment control

When various small companies settle together in an area, they might intensify some environmental impacts but, at the same time, they also increase their scale and have the opportunity of sharing some environmental control infrastructure. Examples of such infrastructure include common wastewater treatment facilities and solid waste disposal sites.

In the Pedro II case, a similar situation has been identified regarding reforestation. After obtaining the environmental permit for the Boi Morto mine, the *garimpeiros* cooperative became bound in remediating its environmental liabilities, including recovering degraded areas. As a strategy it has built a nursery to produce seedlings for reforestation. As miners from other areas also obtain their permits, even if they do not become part of the cooperative, there is the potential for the use of these seedlings in other sites, a practice that was not in place before the cluster.

Diversifying the economy: ecotourism as an alternative for long term development

The long-term economic and social viability of the region would depend on diversifying the economic activities and income in the region to make the economic agents in the cluster less dependent on opal mining, which is a non-renewable resource that will end one day.

Pedro II has a natural vocation for tourism, due to its altitude and mild climate. Additionally, the town has natural highlights, such as the Gritador Range and the Salto Liso Waterfall, which attract people interested in ecotourism. Natural assets are not the only reason behind tourism development in Pedro II, and there are many public policies created to promote the tourism sector and link it to opal activity, such as visit to the mines or local jewellery markets.

Although it should not be considered a panacea, investments in ecotourism seem to be creating positive outcomes. The city has important natural and cultural assets and is located in a region that lacks leisure and tourism alternatives for a growing economic elite. The main strategy to make the region known has been the promotion of the Winter Festival, a mix of music, gems and arts event. Although it is not an alternative to mining yet, ecotourism seems to be a viable way to relate to the environment and improve the local economic performance.

Conclusion

This article aimed at evaluating different aspects of the Opal Cluster Project in Pedro II to understand to what extent the promotion of clusters of small economic agents in the gem sector has brought some improvements in the economic, social and environmental conditions in the mining sector and activities related to it. The historical analysis in Pedro II indicated a long period of government absence, when companies and *garimpeiros* mined opals without any control leaving a track of environmental degradation, mining disasters and overburden public services. As a result, neither the municipality nor the local people benefited fully from the exploitation of Pedro II's natural resources. As an attempt to remediate this situation, public and private actors have developed a series of partnerships among the various stakeholders, creating the Opal Cluster Project. This project attempts to construct a positive agenda, based on solutions developed through joint efforts using the concept of cluster in order to tap on the scale of the small agents and the opportunities for cooperation and diffusion of knowledge. One of the challenges faced by the project is its location, once it has been developed in a very socially vulnerable area, with low levels of income, education and access to public services. The total amount of persons involved in the cluster is not clear, estimates suggest around 400 jobs associated to the opal production chain (Pinto and Feitosa, 2007). Additionally, the Opal Cluster Project increased the economic activities in Pedro II and kept people in town, an important aspect considering the past high rates of migration.

The project has been able to create and adapt innovative solutions that not only ensure its economic feasibility, but also improves its environmental and social performance. The availability of technically qualified staff and financial resources made it possible to address issues such as formalisation, workers safety, water pollution and waste disposal. In spite of these advances, the project still seems to face some challenges, in the short and long term.

Considering more urgent issues, the project still needs to become attractive to more *garimpeiros* and to become economically feasible. Figures indicate that less than 25% of the *garimpeiros* are members of the cooperative, which suggest that many others are still working informally. Therefore, consolidating and expanding the cooperative still seem to be an important step. At the same time, the cluster has been dependent of external financial help (from SEBRAE, FINEP etc.) and decision-makers have to develop a transition strategy to make the project self-sufficient.

On the long term, the main challenge seems to be promoting economic diversity. Opals are non-renewable resources, and the project must consider new strategies in order to avoid a possible boom-collapse process. The case shows that artisanal mining clusters can be an effective strategy to create regulation compliance and to have more efficient activities. Nevertheless, there is still need to encourage other activities, such as tourism, that do not depend on non-renewable resources.

In summary, the main lesson from the study is that policies that promote clusters of artisanal mining are necessary, but not sufficient, strategies to promote local development. Although restrict, they seem an effective way to increase formalisation, enhance information diffusion, develop expertise and improve performance. Nevertheless, in order to become truly sustainable, they also have to create ways to think beyond mining, and to use revenues to create post-extractive economies.

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