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Research paper

"Small in size, but big in impact": Socio-environmental reforms for sustainable artisanal and small-scale mining

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ABSTRACT

Artisanal and small-scale mining (ASM) – small sized, largely unrecognized, rudimentary, and an informal form of mining – occurs in more than 70 countries around the world and is mainly hailed for its socioeconomic benefits and reviled for its environmental devastation. As a result, many people are confused about the future of ASM. In Ghana, the government banned ASM in 2017 and formed a security taskforce drawn from the military and police to crack down on nomadic and local ASM workers who defy the ban. This approach is unsustainable, deals less with the fundamental problems, and increases poverty among the already impoverished local populations who depend on this type of mining as their only means of livelihood. To support the argument for sustainable reforms, revenue growth decomposition and growth accounting analyses were performed to determine the factors shaping ASM revenue over 25 years (1990–2016). Results show that production (gold output) is the most important factor that influences revenue growth from ASM, contrary to the usual view that the price of the metal is mainly responsible for the increase in revenue. Thus, increasing labor hours in ASM could significantly increase mining revenue, reduce unemployment, and improve local commerce. We strongly conclude that sustainable reforms such as increasing local participation in decision making, education and training, adoption of improved technology, strengthening regulatory institutions, legislation and enforcement of enactments, and the provision of technical support and logistics could ensure socio-environmental sustainability.

1. Introduction

Gold mining has been a major contributor to economic development in numerous countries. It provides revenue for governments through earnings from foreign exchange, foreign direct investments, gross domestic product, and employment and income to both a skilled and unskilled workforce. Gold mining in Ghana occurs in two main forms, large-scale mining (LSM), involving heavy mechanization and artisanal and small-scale mining (ASM), typically involving simple hand tools such as pickaxes and shovels for digging gold-bearing materials.

Artisanal and small-scale mining is the oldest form of mining in the country and was practiced in poor rural areas until its recognition and regularization through the enactment of the Small-Scale Gold Mining Law of 1989 (PNDCL 218). Under this law, Ghanaian citizens who are at least 18 years old are required to seek licensure to engage in ASM in the country. Presently, many ASM workers operate without seeking licensure due to certain bottlenecks described as economic, political, social, regulatory, and technological factors by Bansah, Dumakor-Dupey, Kansake, Assan, and Bekui (2018). While about one million people engage in licensed ASM, at least twice that number operate in unlicensed/unregistered ASM (Bansah et al., 2018; Bansah, Yalley, & Dumakor-Dupey, 2016). In addition, there are widespread environmental issues such as heavy metal pollution (Affum et al., 2016; Paruchuri et al., 2010), indiscriminate vegetation removal and the destruction of farmlands (Boadi, Nsor, Antobre, & Acquah, 2016), sedimentation of rivers, improper handling of waste, abandonment of excavated pits, and a lack of reclamation (Bansah, Dumakor-Dupey, Stemn, & Galecki, 2018). These environmental issues are believed to exacerbate the socioeconomic conditions of the people living in these mining-affected communities. For example, Bansah et al. (2018) report increased water pollution and land degradation caused by ASM in southwestern Ghana. These environmental problems have resulted in increased municipal water treatment costs and reduced arable lands.

As a result of these environmental issues and a lack of control over the mining activities, the government of Ghana instituted a ban in March 2017 prohibiting ASM in the country. The ban also aimed to help

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the government to reform the ASM sector. This ban which was intended for a period of six months lasted for almost two years and resulted in a loss of capital, jobs, and income. Hilson (2017) reported the destruction of expensive equipment belonging to ASM workers by a government taskforce tasked with enforcing the ban. This situation worsened the conditions of the already impoverished local communities. Furthermore, a continuous ban on ASM could cause the government to lose more than 30% of the total gold production in the country, which is the contribution made by ASM. While many Ghanaians have called for strict laws which would completely ban ASM in the country due to environmental issues, many are also of the view that ASM could act as a cornerstone for poverty reduction in poor rural communities. We believe that sustainable reforms would minimize the environmental issues and improve the economic benefits of mining activities.

To support this view, a growth decomposition model was employed. This model has widely been used in growth and development literature to measure the relative contribution of "within-sector" factors (consequences of technological progress, increased efficiency, or reduced misallocation) and "between-sector" factors (resulting from labour reallocation across sectors) to overall economic growth (De Vries, Timmer, & De Vries, 2015; Diao & McMillan, 2018; McCaig, McMillan, Verduzco-Gallo, & Jefferis, 2015). This economic model was adopted to assess the performance of ASM in Ghana over the past 25 years. The model separately quantifies the relative contributions of price and output (production) to growth in revenue and decomposes the growth in revenue into three constituents: (i) price effect, (ii) output (production) effect, and (iii) correlation effect. This growth decomposition model provides a framework to study the forces shaping the economic incentives of the ASM actors. By way of definition, price effect is the change in total revenue resulting from price appreciation when production (output) is kept constant, while output effect involves the change in total revenue resulting from output growth when the price is kept constant. Correlation effect measures the change in total revenue from both price change and output growth. Thus, the model provides a systematic way of quantifying the relative contributions of metal prices and production surge to the performance of growth in revenue from ASM.

Presently, there is a lack of scientific work on the quantitative assessment of the main factors accounting for revenue growth in mining. One study by Owusu, Wireko, and Mensah (2016) performed a quantitative assessment of the sources of growth in large-scale multinational gold mining revenue. In ASM, several pieces of literature have narrated the contributions of mining to economic growth (Bansah et al., 2018; Boadi et al., 2016; Kamlongera, 2011). Kamlongera (2011) indicated that ASM provided employment to rural people, enhanced family incomes, and improved the livelihood of rural people in Malawi. Boadi et al. (2016) indicated that ASM improved income, employment opportunities, and market activities in communities where the mining occurs. Similarly, Bansah et al. (2018) found that ASM provided employment and income opportunities to many unskilled workers in rural communities and served as a significant source of revenue to the Ghanaian government. Quantitative assessment to determine the source (s) of growth in revenue in ASM is noticeably absent in the literature. Thus, the growth decomposition model, data from international/regulatory institutions, and literature are used to quantitatively assess the performance of the ASM sector in Ghana, evaluate the relative contributions of price and production to revenue growth, and to inform policy towards sustainable reforms.

2. Methods

This section describes the data used in the study and the methods adopted to achieve the objectives of the study. Following data acquisition from international and regulatory institutions, decomposition analysis, using a growth decomposition model, was performed. This was followed by growth accounting analysis to validate the results of the growth decomposition analysis.

Table 1
ASM gold production, nominal gold prices, and CPI inflation rates (1990–2016).

Year	ASM gold production ("000")	Nominal gold price[a] ($/ounce)	CPI inflation rate[b] (%)
1990	17.23	383.60	37.26
1991	15.60	362.30	18.03
1992	17.30	344.00	10.06
1993	35.15	359.80	24.96
1994	89.52	384.20	24.87
1995	127.03	384.10	59.46
1996	112.35	387.90	46.56
1997	107.10	331.30	27.89
1998	128.33	294.10	14.62
1999	130.83	278.60	12.41
2000	145.66	279.10	25.19
2001	185.60	271.00	32.91
2002	160.88	309.70	14.82
2003	221.06	363.30	26.67
2004	246.57	409.20	12.62
2005	225.41	444.50	15.12
2006	247.06	603.80	10.92
2007	388.59	695.40	10.73
2008	418.94	872.00	16.52
2009	555.74	972.40	19.25
2010	767.20	1,224.50	10.71
2011	978.61	1,571.50	8.73
2012	1,495.33	1,669.00	9.16
2013	1,578.44	1,411.20	11.61
2014	1,512.52	1,266.40	15.49
2015	1,031.18	1,160.10	17.15
2016	1,600.00	1,250.80	17.47

ASM gold production data was obtained from MinCom (1990–2014) [Retrieved October 3, 2018 from www.mofep.gov.gh/sites/default/files/reports/economic/ASM%20FRAMEWORK.pdf.], GHEITI (2015) [Retrieved October 3, 2018 from eiti.org/sites/default/files/documents/2015_gheiti_mining_report.pdf.], and the Former CEO of Minerals Commission of Ghana (2016); $ = USD.

[a] Retrieved September 30, 2018 from www.gold.org/data/gold-price.

[b] Retrieved September 30, 2018 from data.worldbank.org/indicator/FP.CPI.TOTL.ZG?view = chart.

2.1. Research data

Data used for this study included historical ASM gold production, gold prices, and consumer price index (CPI) inflation rates (Table 1). The ASM gold production data was obtained from the Minerals Commission of Ghana (MinCom) and Ghana Extractive Industries Transparency Initiative (GHEITI), while data on market (nominal) prices of gold were obtained from the World Gold Council (WGC). The CPI-based inflation rates were acquired from World Development Indicators. The data covered a 25-year period from 1990 to 2016. ASM production data for the years beyond 2016 was not available at the time of this study, and therefore could not be included.

2.2. Growth decomposition analysis

Growth decomposition analysis was performed using Equation (1). The revenue (R) in time t is determined as the product of price (P) and quantity (Q) as follows:

$$R_t = P_t Q_t \quad (1)$$

Quantity (Q) is the total output of gold measured in ounces, and price (P) is the market price of gold measured in USD per ounce. The change in revenue is decomposed into price effect, output effect, and correlation effect to obtain the decomposition model in Equation (2).

$$\Delta R_t = Q_{t-k}\Delta P_t + P_{t-k}\Delta Q_t + \Delta Q_t \Delta P_t \quad (2)$$

Equation (2) states that change in total revenue is the result of price appreciation/depreciation ($Q_{t-k}\Delta P_t$), production growth ($P_{t-k}\Delta Q_t$) or a combination of both factors ($\Delta Q_t \Delta P_t$). The first component ($Q_{t-k}\Delta P_t$) is the price effect which captures the growth in revenue due to price growth (appreciation or depreciation) while holding the production (output) level constant. It is calculated as the product of the change in price (ΔP_t) at time t and the production level (Q_{t-k}) at time t-k. The second component is the output effect ($P_{t-k}\Delta Q_t$) and this measures the change in total revenue from growth in production while keeping prices constant. It is calculated as the product of the price level at time t-k (P_{t-k}) and the change in production at time t (ΔQ_t). The third component is the correlation effect ($\Delta Q_t \Delta P_t$) and this captures the change in total revenue resulting from a combination of a change in price and a change in production. It is calculated as the product of the change in price (ΔP_t) at time t and the change in production (ΔQ_t) at time t.

The contribution of each component to revenue growth depends on the direction (sign) and the magnitude of the change. A positive value enhances revenue growth, while a negative value depresses revenue growth. Additionally, the larger the magnitude, the greater the relative contribution to revenue growth. Revenue growth is magnified when the correlation between the price level and production is positive (i.e. they move in the same direction), while it is impeded when the price level and production are negatively correlated (i.e. the move in the opposite direction). It can be deduced that the contribution of the correlation effect is largely dependent on the magnitude and direction of the change in price and production. Thus, the correlation effect reinforces the price and output effects when positive and partially offsets their contributions when negative.

2.3. Growth accounting analysis

The growth accounting technique was employed to complement the results of the decomposition analysis. This was performed by decomposing the growth in revenue into price growth and output growth. Hence, Equation (1) was decomposed as follows:

Total change in revenue is determined as

$$dR_t = \frac{\partial R_t}{\partial P_t} dP_t + \frac{\partial R_t}{\partial Q_t} dQ_t \tag{3}$$

Hence,

$$dR_t = Q_t dP_t + P_t dQ_t \tag{4}$$

Dividing Equation (4) by R_t yields

$$dR_t \Big/ R_t = \frac{Q_t}{P_t Q_t} dP_t + \frac{P_t}{P_t Q_t} dQ_t = \frac{1}{P_t} dP_t + \frac{1}{Q_t} dQ_t \tag{5}$$

This equation reduces to

$$R_g = P_g + Q_g \tag{6}$$

Thus, growth in revenue (R_g) is determined as the sum of price growth (P_g) and output growth (Q_g). However, unlike the growth decomposition analysis, the growth accounting technique does not take into account the correlation effect between production decisions and gold prices, which can have a profound effect on production decisions.

3. Results

Table 2 contains real gold prices, nominal revenue, and real revenue from 1990 to 2016. Nominal revenue was obtained by multiplying production with the market price (nominal) of gold. To obtain real revenue, the nominal price of gold was deflated by CPI inflation rate to obtain the real gold price. This real gold price was then multiplied by ASM gold production to obtain real revenue.

Table 2
Real gold prices, nominal and real revenue from ASM gold production (1990–2016).

Year	Real gold price ($/ounce)	Nominal revenue ($M)	Real revenue ($M)
1990	279.47	6.61	4.82
1991	306.95	5.65	4.79
1992	312.57	5.95	5.41
1993	287.93	12.65	10.12
1994	307.68	34.39	27.54
1995	240.87	48.79	30.60
1996	264.67	43.58	29.74
1997	259.06	35.48	27.74
1998	256.58	37.74	32.93
1999	247.85	36.45	32.43
2000	222.94	40.65	32.47
2001	203.90	50.30	37.84
2002	269.74	49.82	43.39
2003	286.80	80.31	63.40
2004	363.33	100.90	89.59
2005	386.12	100.20	87.04
2006	544.38	149.18	134.50
2007	628.00	270.23	244.04
2008	748.36	365.32	313.52
2009	815.42	540.40	453.16
2010	1,106.07	939.43	848.57
2011	1,445.37	1,537.89	1,414.45
2012	1,528.94	2,495.70	2,286.26
2013	1,264.42	2,227.50	1,995.82
2014	1,096.52	1,915.45	1,658.50
2015	990.31	1,196.27	1,021.18
2016	1,064.75	2,001.28	1,703.60

3.1. Historical gold prices: nominal and real gold prices

The trends in nominal and real gold prices from 1990 to 2016 are presented in Fig. 1. From 1990, the nominal gold price consistently remained below $1000 per ounce until 2010 and peaked at $1669.0 per ounce in 2012. The nominal gold price rose from $383.6 per ounce in 1990 to $1250.8 per ounce in 2016. Over this same period, the nominal price of gold grew at an annualized rate of 4.5%. Between 1990 and 2005, the nominal gold price remained stable and grew marginally at 1.0% per year. There was a strong appreciation in the nominal gold price from 2005 to 2012 with an annualized rate of 18.9%. The nominal gold price declined by almost 25% between 2012 and 2016. The real gold prices followed a similar trend as the nominal gold prices. However, the real gold prices were consistently lower than their corresponding nominal gold prices. The real gold price over the 25-year period was lowest in 2001 at $203.9 per ounce and highest in 2012 at about $1528.9 per ounce.

3.2. ASM contribution to total gold production

Gold production from ASM with its corresponding percentage contribution to total gold produced in the country from 1990 to 2016 is presented in Fig. 2. Gold production from ASM in 1990 was below 20,000 ounces, and this accounted for less than 5% of the total gold produced that year. Over the years, there was a steady increase in gold production, peaking at 1,578,440 ounces with a corresponding contribution of 35% to total gold production in the country. Gold production gradually declined after reaching its peak in 2012 and sharply dropped to a little over one million ounces in 2015, resulting in less than 30% of the total gold production. In 2016, gold produced from ASM increased significantly to 1.6 million ounces, accounting for close to 40% of the total gold produced in the country.

3.3. Revenue from ASM gold production

The trend in total revenue accruing from ASM gold production from 1990 to 2016 is presented in Fig. 3. Nominal revenue increased from

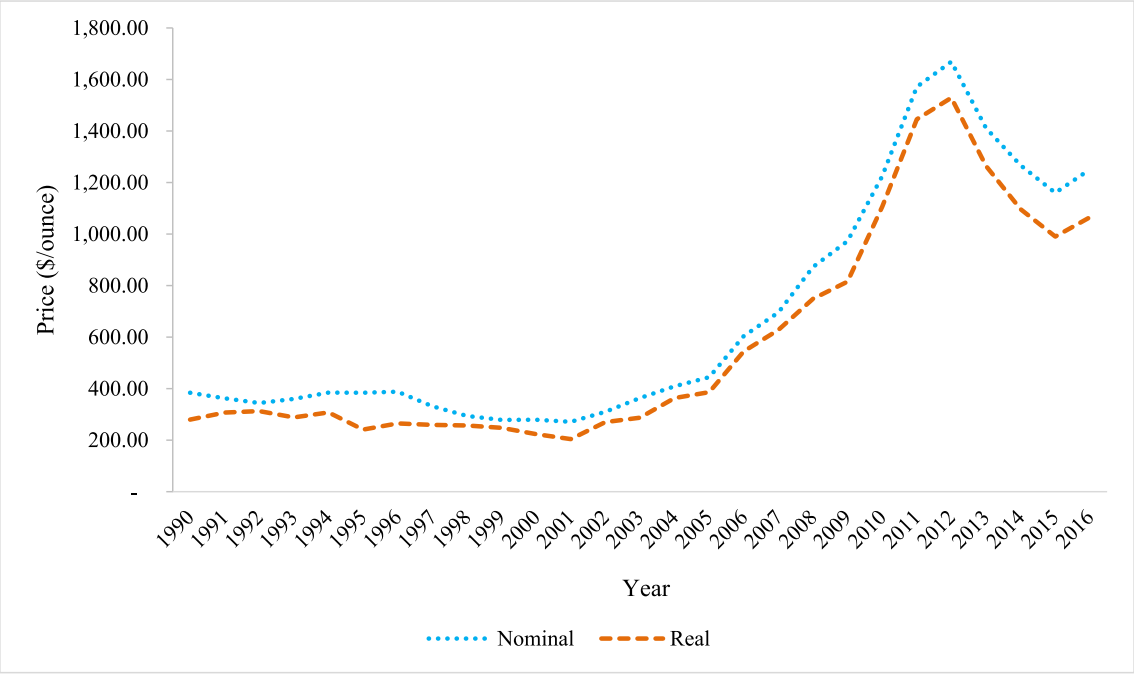

Fig. 1. Nominal and real gold prices from 1990 to 2016.

USD 6.6 million in 1990 to USD 2.0 billion in 2016. Over this period, nominal revenue grew at an annualized rate of 22%. From 1990 to 2005, nominal revenue grew at a rate of 18% per year, while it rapidly increased to 50% per year between 2005 and 2012. Between 2012 and 2015, nominal revenue declined by almost 50% but bounced back in 2016. The trend in real revenue is similar to the trend observed in nominal revenue over the same period. Real revenue grew at an annualized rate of about 23% over the period. Between 1990 and 2005, real revenue grew at 19% per year, while the annualized growth rate between 2005 and 2015 was about 47%. Between 2012 and 2015, real revenue declined by almost 70% before surging in 2016.

3.4. Revenue growth decomposition analysis

As previously stated, the revenue growth decomposition analysis provides a means of performing the quantitative assessment of price and production and the forces driving ASM revenue growth. Results from this revenue growth decomposition analysis are presented in Table 3. These results show that the output effect, price effect, and the correlation effect contributed positively to growth in ASM revenue. However, the relative contributions of the correlation effect (15.1%) and the output effect (6.7%) were significantly stronger than the contribution of price effect (0.2%) over the period. While the output effect accounted for a little over 30% of the annualized nominal revenue growth, price effect accounted for only 0.7% of the annualized growth.

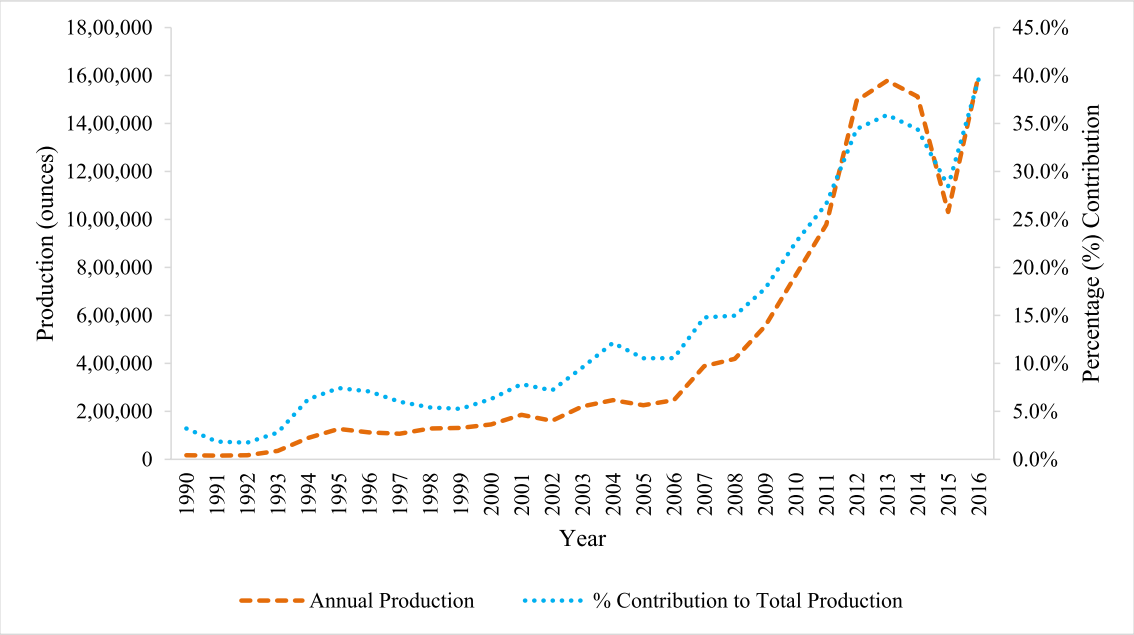

Fig. 2. The contribution of ASM to the total gold production in Ghana from 1990 to 2016.

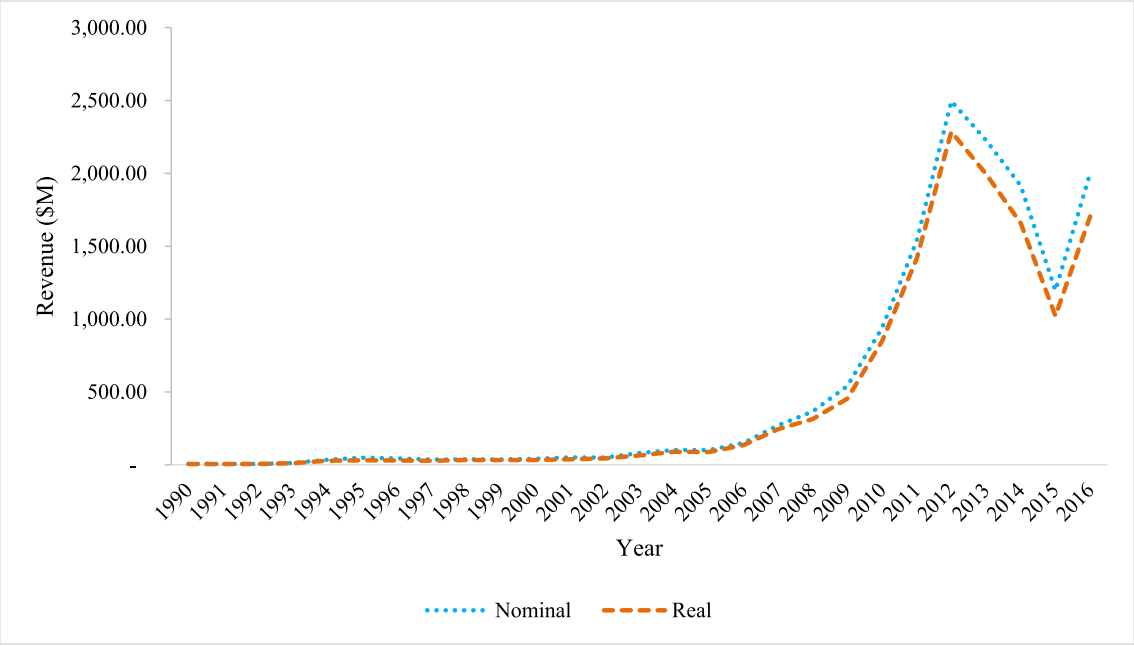

Fig. 3. Total revenue from ASM gold production in Ghana from 1990 to 2016.

Table 3
Decomposition of ASM revenue growth into price, output, and correlation effects.

Year	Output effect	Price effect	Correlation effect	Overall revenue growth
1990–2000	26.3	−1.0	−7.2	18.2
2000–2010	6.1	4.8	20.5	31.4
2010–2016	12.1	0.2	0.3	12.6
1990–2016	6.7	0.2	15.1	22.0
% Contribution (1990–2016)	**30.4**	**0.7**	**68.8**	**100.0**

Table 4
Robustness analysis using real prices.

Year	Output effect	Price effect	Correlation effect	Overall revenue growth
1990–2000	24.8	−0.7	−5.0	19.1
2000–2010	5.5	5.1	21.9	32.6
2010–2016	12.5	−0.4	−0.5	11.6
1990–2016	5.9	0.2	16.5	22.6
% Contribution (1990–2016)	**26.0**	**0.8**	**73.2**	**100.0**

The annualized correlation effect over the period was approximately 69%.

The decade-by-decade analysis further reveals significant differences in the dynamics of the contributions to nominal revenue growth. The price-output correlation between 1990 and 2000 was negative; production surged, while gold price declined by almost 30%. Over the same period, revenue grew at a rate of 18% per year. The growth in revenue from the output effect was approximately 26% per year. The relative contributions of the price and correlation effects were, respectively, −1.0% and −7.2% per year, partially offsetting the strong contribution from the output effect. Between 2000 and 2010, price and output were positively correlated, and this amplified the sector's overall revenue growth. While nominal revenue grew at 31.4% per year, both price and output effect accounted for only 10.9% of this growth. The remaining 20.5% of the growth was accounted for by the correlation effect. Between 2010 and 2016, growth in revenue resulted mostly from production surge; accounting for more than 90% of the annualized growth in nominal revenue. The combined contribution from the price and correlation effects was less than 5% over this period.

Table 4 provides further robustness analysis using real prices of gold. The real price of gold in each year was obtained by deflating the nominal price in each year by an inflation factor (1 + inflation rate). Real revenue is then calculated by multiplying the real price in each year by the corresponding production/output level. The results are broadly consistent and robust. The relative contribution of the correlation effect was dominant and accounted for 73.2% of the annualized growth in real revenue. The contribution of the output effect was 26.0% and of the price effect was 0.8%. The decade-by-decade analysis revealed a strong contribution from production surge between 1990 and 2000 and between 2010 and 2016.

3.5. Revenue growth accounting

Revenue growth accounting was performed in order to validate the results from the revenue growth decomposition method. This accounting technique decomposed growth in revenue into price growth and output growth, as shown in Table 5. The results show that growth in revenue has resulted more from output growth than price growth. Growth in production accounted for approximately 80% of the growth in real revenue and nominal revenue over the period. This result is partly consistent with the growth decomposition analysis which indicated a relatively higher contribution from output effect than price effect.

4. Discussion

It is evident in this study that ASM has consistently contributed to gold mining revenue in Ghana and, presently, accounts for close to 40% of the total gold produced in this West African country. It is also clear from this study that ASM production increased substantially over the years from less than 20,000 ounces in 1990 to 1.6 million ounces in 2016. This increased production corresponded with a significant increase in revenue over the period. The increasing levels of production in

Table 5
Contributions of price and output based on growth accounting.

Year	Output growth	Nominal price growth	Nominal revenue growth	Output growth	Real price growth	Real revenue growth
1990–2000	21.3	−3.2	18.2	21.3	−2.3	19.1
2000–2010	16.6	14.8	31.4	16.6	16.0	32.6
2010–2016	12.3	0.4	12.6	12.3	−0.6	11.6
1990–2016	17.4	4.5	22.0	17.4	5.1	22.6
% Contribution (1990–2016)	**79.3**	**20.7**	**100.0**	**77.2**	**22.8**	**100.0**

ASM could be attributed to the increasing number of unemployed youth rushing into the sector and the increasing adoption of advanced or semi-mechanized tools and technology in mining processes. The adoption of less labor-intensive techniques could improve gold production. As Bansah et al. (2018) indicated, many people rush into ASM due to increasing poverty in the country. Although there is increased adoption and utilization of more complex tools in ASM, the sector is still largely labor-intensive. Thus, increased production could typically be attributed to increased labor hours. For example, the increased crackdown on informal ASM participants in 2015 by a combined military and police taskforce formed by the central government could be connected to the momentous decline in ASM production that year. This is because many of the miners were arrested by the taskforce and their tools seized or destroyed. In contrast, ASM production surged significantly in the national election year of 2016, and this can be attributed to increased participation in ASM when the government withdrew security forces from the ASM communities. Therefore, it is our view that increased participation by many unskilled workers and the unemployed youth is largely responsible for the increased production in ASM over the years.

As previously described, revenue is the product of gold produced and unit price of gold. Thus, revenue is directly proportional to the quantity of gold produced and the unit price of gold. However, as evidenced in the revenue growth decomposition and growth accounting analyses, gold production (output) is the main controlling factor of gold revenue in the country. Even though gold price is an important parameter in the revenue equation, the data analyses indicate that revenue is largely controlled by the quantity of gold produced. Thus, increasing labour hours could yield high production and large revenues. Labour hours can, in turn, be increased by employing more people to work in ASM. The utilization of heavy mining equipment such as excavators and dozers in ASM could help boost production. Nonetheless, the adoption of heavy earthmoving equipment has been linked to increased environmental degradation (Bansah et al., 2016, 2018). Therefore, a more plausible alternative is to increase labor in ASM. A thriving ASM sector could help improve the serious unemployment situation in the country. Recently, the government launched a program called Nations Builders Corp (NaBCo) aimed to reduce graduate unemployment in the country. This government "flagship program" is scheduled to provide an income of GHS 700 (USD 144) per month to each participant regardless of the nature of work or standard and cost of living. Informal ASM provides typical incomes between GHS 1,000 and GHS 5,000 per month. Hence, an improved ASM sector could attract many of these university graduates who have lost hope of securing financial independence and this would minimize youth unemployment in the country.

Therefore, the government of Ghana should quickly reform the sector to increase the benefits the sector brings to the local and national economy. The ban and subsequent use of security forces to "fight" ASM, according to the government, was brought about by the level of environmental degradation caused by the mining activities. We believe that a ban and a military approach are unsustainable because there are still many miners operating in many different places in the country which still experience environmental destruction. A concerted effort must, therefore, be made to ensure that the ASM sector is recognized, regulated, accepted, and integrated into the larger mining spectrum in the country. A military approach is ad hoc, lacks effective consultation and community participation, is short-term and short-lived, is unplanned, and unsustainable in the long term. Geenen (2012) shared similar views when she described a ban on ASM in the Democratic Republic of Congo as radical and failing to address different problems associated with ASM. Sustainable reforms would improve environmental performance, sustainability, and the socioeconomic benefits of the sector.

A well-formalized and regulated ASM sector could reduce the environmental impacts associated with the activities and serve as a useful poverty alleviation alternative in many poor rural communities in the country. Additionally, ASM could complement small and medium-size enterprise projects. As suggested by Bansah et al. (2018) and Wilson, Renne, Roncoli, Agyei-Baffour, and Tenkorang (2015), revenues from ASM can be reinvested locally for social interventions, infrastructural development, and environmental protection and management. ASM could serve as a driver of demand for goods and services to create business opportunities and niche markets for individuals in the local communities. Thus, ASM can generate purchasing power for locals by engaging in income-generating ventures such as business services, retail stores, food vending, hotels, and restaurants. It is thus argued that ASM has the potential to reduce poverty through the provision of fiscal revenues for investment in health care and education, by providing an economic boost and growth in mining communities, by offering direct employment to locals, and by providing private investments in public goods.

Reforms to ensure the sustainability of ASM could include encouraging local community participation in resource management, the education and training of stakeholders, increasing the use of technology, strengthening regulatory institutions and oversight, and the provision of technical support for the miners. For example, educating the miners about finance and accounting could help them prepare financial documentations to secure funding from banks or financial institutions to support their mining activities. Additionally, a mercury-free gold processing technique, such as the one developed by Veiga et al. (2018), could be evaluated and tested for its suitability in the Ghanaian context with the aim of its possible adoption to eliminate the toxic mercury substance from gold processing and to improve the health and safety of the miners and protect the environment.

As stated by Bansah et al. (2018), a lack of environmental protection enactments and poor regulatory enforcement have partly been blamed for the poor environmental performance in ASM. This situation can be improved through sustainable reforms. For example, the lack of reclamation, one of the major means through which ASM pollutes the environment, could be improved via proper planning, appropriate and accessible legislations, and enforcement. Synchronizing mining and environmental care could alleviate environmental degradation and its effects. Thus, ASM workers could be mandated by law to conduct mining concurrently with environmental remediation under the supervision of competent personnel. Whilst reclamation can incur significant costs, an improved ASM sector with strong finances and improved revenue can undertake reclamation to restore the productive capacity of the soils for farming, or for alternative post-mining land uses such as cultural centers and amusement parks or restore the degraded lands to their pre-mining uses. Additionally, cheaper and cleaner technologies, such as phytoremediation and the application of biochar, can be adopted to immobilize heavy metals in the degraded soils, amend soil physicochemical properties, help to establish

vegetation (forest) cover, minimize heavy metal pollution, and even improve climate change. Phytoremediation, a technique involving the use of plants to clean contaminated soils can be employed successfully in mine degraded landscapes in the country due to the availability and accessibility of indigenous plants capable of absorbing heavy metals from soils and relocating them to their aboveground parts. Bansah and Addo (2016) observed that native plant species, such as *Xylopia aethiopica, Pityrogramma calomelanos, Chromolaena Odorata, Leucaena leucocephala,* and *Terminalia superba* which grow very well in Ghana, are highly suitable for cleaning copper, cadmium, lead, manganese, and iron contaminated sites. Mensah and Frimpong (2018) found that biochar-charcoal produced from anaerobic combustion (pyrolysis) of biomass – improved soil properties and could be adopted to ensure sustainable agriculture in Ghana. In a tropical rainforest environment, biomass is readily available and can be used to produce biochar on a large scale to serve the ASM sector and local farming communities. Additionally, ASM workers can produce biochar to serve the industry. This biochar can even serve as an alternative source of income for the miners by selling it to nearby farmers or it could be given to the local communities as a form of social support to improve their largely informal farming methods.

5. Conclusion

Revenue growth decomposition and growth accounting analyses were performed to determine the major factor(s) influencing growth in revenue in ASM over a period of 25 years. Revenues from Ghana's ASM sector over the period were decomposed into price effect, output (production) effect, and correlation effect. The major finding is that output effect is the single most important parameter influencing growth in revenue in ASM. This finding is in sharp contrast with the commonly held view that increasing gold prices, in the international market, account for increased revenue in ASM. Although gold price plays an important role in mining revenue, it is observed in this study that increased revenues in ASM are largely due to increased production. Thus, reforms which can increase labour hours in ASM would improve revenue, increase local commerce, and reduce unemployment. It is further argued that ASM is an important source of livelihood for many rural populations; thus, the continuous ban on ASM in the country could lead to a devastating effect on the lives of the locals who engage in these activities. As its name suggests, ASM is small in size but can produce big impacts. Therefore, sustainable reforms, including increased local participation in decision making, education and training, adoption of improved technology, strengthening regulatory institutions, legislation and the enforcement of enactments, and provision of technical support and logistics could help to improve socioeconomic and environmental performance.

Conflicts of interest

None declared.

Ethical statement

Authors state that the research was conducted according to ethical standards.

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Appendix A. Supplementary data

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References

Affum, A. O., Dede, S. O., Nyarko, B. J. B., Acquaah, S. O., Kwaansa-Ansah, E. E., Darko, G., ... Fianko, J. R. (2016). Influence of small-scale gold mining and toxic element concentrations in Bonsa river, Ghana: A potential risk to water quality and public health. *Environmental Earth Sciences, 75*(2), 178. https://doi.org/10.1007/s12665-015-5000-8.

Bansah, K. J., & Addo, W. K. (2016). Phytoremediation potential of plants grown on reclaimed spoil lands. *Ghana Mining Journal, 16*(1), 68–75. https://doi.org/10.4314/gm.v16i1.8.

Bansah, K. J., Dumakor-Dupey, N. K., Kansake, B. A., Assan, E., & Bekui, P. (2018a). Socioeconomic and environmental assessment of informal artisanal and small-scale mining in Ghana. *Journal of Cleaner Production, 202*, 465–475. https://doi.org/10.1016/j.jclepro.2018.08.150.

Bansah, K. J., Dumakor-Dupey, N. K., Stemn, E., & Galecki, G. (2018b). Mutualism, commensalism or parasitism? Perspectives on tailings trade between large-scale and artisanal and small-scale gold mining in Ghana. *Resources Policy, 57*, 246–254. https://doi.org/10.1016/j.resourpol.2018.03.010.

Bansah, K. J., Yalley, A. B., & Dumakor-Dupey, N. (2016). The hazardous nature of small-scale underground mining in Ghana. *Journal of Sustainable Mining, 15*(1), 8–25. https://doi.org/10.1016/j.jsm.2016.04.004.

Boadi, S., Nsor, C. A., Antobre, O. O., & Acquah, E. (2016). An analysis of illegal mining on the Offin shelterbelt forest reserve, Ghana: Implications on community livelihood. *Journal of Sustainable Mining, 15*(3), 115–119. https://doi.org/10.1016/j.jsm.2016.12.001.

De Vries, G., Timmer, M., & De Vries, K. (2015). Structural transformation in Africa: Static gains, dynamic losses. *Journal of Development Studies, 51*(6), 674–688. https://doi.org/10.1080/00220388.2014.997222.

Diao, X., & McMillan, M. (2018). Toward an understanding of economic growth in Africa: A reinterpretation of the Lewis model. *World Development, 109*, 511–522. https://doi.org/10.1016/j.worlddev.2016.12.008.

Geenen, S. (2012). A dangerous bet: The challenges of formalizing artisanal mining in the Democratic Republic of Congo. *Resources Policy, 37*(3), 322–330. https://doi.org/10.1016/j.resourpol.2012.02.004.

Hilson, G. (2017). Shootings and burning excavators: Some rapid reflections on the government of Ghana handling of the informal galamsey mining 'menace'. *Resources Policy, 54*, 109–116. https://doi.org/10.1016/j.resourpol.2017.09.009.

Kamlongera, P. J. (2011). Making the poor, 'poorer' or alleviating poverty? Artisanal mining livelihoods in rural Malawi. *Journal of International Development, 23*(8), 1128–1139. https://doi.org/10.1002/jid.1836.

McCaig, B., McMillan, M. S., Verduzco-Gallo, I., & Jefferis, K. (2015). *Stuck in the middle? Structural Change and productivity Growth in Botswana (No. w21029)*. National Bureau of Economic Research.

Mensah, A. K., & Frimpong, K. A. (2018). Biochar and/or compost applications improve soil properties, growth, and yield of maize grown in acidic rainforest and coastal savannah soils in Ghana. *International Journal of Agronomy*. 2018 https://doi.org/10.1155/2018/6837404.

Owusu, O., Wireko, I., & Mensah, A. K. (2016). The performance of the mining sector in Ghana: A decomposition analysis of the relative contribution of price and output to revenue growth. *Resources Policy, 50*, 214–223. https://doi.org/10.1016/j.resourpol.2016.10.006.

Paruchuri, Y., Siuniak, A., Johnson, N., Levin, E., Mitchell, K., Goodrich, J. M., ... Basu, N. (2010). Occupational and environmental mercury exposure among small-scale gold miners in the Talensi-Nabdam District of Ghana's Upper East region. *The Science of the Total Environment, 408*(24), 6079–6085. https://doi.org/10.1016/j.scitotenv.2010.08.022.

Veiga, M. M., Masson, P., Perron, D., Laflamme, A. C., Gagnon, R., Jimenez, G., et al. (2018). An affordable solution for micro-miners in Colombia to process gold ores without mercury. *Journal of Cleaner Production, 205*, 995–1005. https://doi.org/10.1016/j.jclepro.2018.09.039.

Wilson, M. L., Renne, E., Roncoli, C., Agyei-Baffour, P., & Tenkorang, E. Y. (2015). Integrated assessment of artisanal and small-scale gold mining in Ghana – Part 3: Social sciences and economics. *International Journal of Environmental Research and Public Health, 12*(7), 8133–8156. https://doi.org/10.3390/ijerph120708133.