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Waldo Mendoza Bellido y
Erika Collantes Goicochea

DEPARTAMENTO DE ECONOMÍA
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RESUMEN

En este documento se presenta un modelo teórico acerca de la inversión en el sector minero y el sector vivienda. La demanda de inversión en la minería, una demanda derivada de la producción minera, limitada por un factor de producción no renovable, se financia a la tasa de interés fijada por el mercado mundial. En el sector vivienda, el precio y el volumen de inversión se determinan en el mercado local, por oferta y demanda.

El modelo muestra la fuerte dependencia de la inversión minera y de viviendas respecto a las condiciones internacionales. Así mismo, la existencia de un factor de producción minero no renovable implica que, con el transcurso del tiempo, si no se descubren nuevas minas, debe reducirse la inversión en minería y viviendas.

Palabras clave: Inversión en el sector minero, inversión en el sector viviendas, recursos no renovables.
Códigos JEL: E22, L72, L74.

ABSTRACT

This paper presents a theoretical model about investment in the mining sector and the housing sector. The demand for investment in mining, a demand derived from mining production, limited by a non-renewable production factor, is financed at the interest rate fixed by the world market. In the housing sector, the price and volume of investment are determined in the local market, by supply and demand.

The model shows the strong dependence on mining investment and the housing of international conditions. Likewise, the existence of a non-renewable mining production factor implies that, with the passage of time, if new mines are not discovered, investment in mining and housing should be reduced.

Keywords: Investment in the mining sector, investment in the housing sector, non-renewable resources.
JEL Codes: E22, L72, L74.

PRIVATE INVESTMENT IN A MINING EXPORT ECONOMY: A MODEL FOR PERU

Waldo Mendoza Bellido y Erika Collantes Goicochea[1]

INTRODUCTION

Peru is a mining export economy in which minerals account for around 60% of all exports. What are the determinants of private investment in a mining export economy that also has a major housing construction industry? And what weight do international and domestic factors have in its determination?

The central aim of this paper is to construct a theoretical model that answers these questions analytically. The model contains two types of investment: investment in the mining sector, linked to the international market; and investment in the housing sector, linked to the internal market.

Production in the mining sector, limited by a non-renewable natural resource with a fixed period of depletion, is wholly destined for export at a price determined by international demand. Investment demand in this sector is derived from mining production, financed at the interest rate set by the international market. In the housing sector, the price and volume of investment are determined in the local market, by supply and demand.

This paper is structured as follows. In the first section we present the theoretical model. In the second section we perform some comparative statistical exercises to study the effect that the change in international conditions and the process of depletion of a non-renewable resource have on private investment. Finally, there is a third section of conclusions.

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## 1. THE MODEL

There are two types of investment in this economy. Investment in the mining sector, connected to the external market; and investment in the housing sector, connected to the internal market. In the model, the treatment of the two types of investment is asymmetric. Mining investment is dominant: it affects, but is not affected by, what occurs in the housing construction sector.

In the tradable sector of the economy, mining-sector production is entirely bound for export at a price determined by international demand. Investment demand in this sector is derived from mining production, financed at the interest rate set by the international market. In the housing sector, the price and volume of investment are determined in the local market, by supply and demand.

### 1.1 Mining investment

We assume a small open economy in the goods markets and in the financial markets. In the goods market, mining production is wholly destined for export at a price given by the world market; and in the financial market, there is external financing for investment in this sector at the current international interest rate.

*The mining export sector*

Let us consider the following production function of a mining product, "processed ore" — an adaptation of chapter 7.2 of Sorensen and Whitta-Jacobsen (2008), drawing on the Solow model in the presence of a non-renewable production factor.

$$Y_t = HK_t^{\alpha}L_t^{\beta}M_t^{\gamma};\ \alpha + \beta + \gamma = 1 \qquad (1)$$

In this equation, $Y_t$ is the volume of production of processed ore, $H$ the complementary public infrastructure for mining activity[2], $K_t$ the stock of capital necessary for the export

[2] In Jones (1997), chapter 7, it is shown how infrastructure, in its broadest expression, fosters the productivity of the production factors. In this model we focus our attention on public infrastructure. From there, it is inferred that there is complementarity between public and private investment.

of ore, $L_t$ the labor employed in mining, and $M_t$ is the non-renewable production factor, the "crude ore" used in the production process.

Given the presence of a non-renewable natural resource as a production factor, we must propose an equation that models the use and the period of depletion of that resource. Equation (2) establishes that at the beginning of the period $t+1$, the stock of crude ore $(R_{t+1})$ is equal to the stock existing in the previous period $(R_t)$, less the part used in the production process during that period $(M_t)$. That is,

$$R_{t+1} = R_t - M_t \quad (2)$$

If it is assumed that a constant fraction $\delta$ of the existing crude ore reserves is used in each period, then,

$$M_t = \delta R_t; 0 < \delta < 1 \quad (3)$$

That is,

$$R_{t+1} = (1-\delta)R_t \quad (4)$$

Given this rule of crude ore extraction, the growth rate of the quantity of resources is constant and equal to – $\delta$. This means that the stock of this resource has its own dynamic. Based on an initial value of $R_0$, the stock of mineral resources evolves according to the following formula,

$$R_t = (1-\delta)^t R_0 \quad (5)$$

The mineral resource usage flow will therefore be given by,

$$M_t = \delta(1-\delta)^t R_0 \quad (6)$$

By replacing equation (6) in the production function (1), we arrive at the following expression with the determinants of processed ore production in this economy.

$$Y_t = HK_t^{\alpha} L_t^{\beta} [\delta(1-\delta)^t R_0]_t^{\gamma} \tag{7}$$

All of the processed ore produced is exported. Since the context is a small open economy, the product is sold at a price determined by international demand.

$$P_x^* = P_{x0}^* \tag{8}$$

*Investment in the mining sector*

The mining company's profit in dollars is given by the difference between the income from the sale of processed ore $(P_x^* Y)$ and the variable costs, which we limit to those arising from the capital, financed entirely by external loans at the international interest rate $r^*$. That is,

$$\Pi^Y = P_x^* Y - r^* K \tag{9}$$

A mining company that seeks to maximize its profits must select the ideal level of investment, such that the value of the marginal product of capital is equal to the international interest rate. That is,

$$P_x^* Y_k = r^* \tag{10}$$

In turn, the marginal product of capital is obtained from equation (1) and is given by,

$$Y_k = \frac{\alpha Y_0}{K} \tag{11}$$

Where $Y_0 = HK_0^{\alpha} L_0^{\beta} M_0^{\gamma} = HK_0^{\alpha} L_0^{\beta} [\delta(1-\delta)^t R_0]_0^{\gamma}$ is mining production in the initial situation. Note that the extraction rule for the metal ore means that mining production tends to zero $(Y_0 \to 0)$ as time tends to infinity $(t \to \infty)$.

In consequence, the desired or optimal capital stock $(K^o)$, that which maximizes the mining company's profits, is equal to,

$$K^o = \frac{P_x^* \alpha Y_0}{r^*} = \frac{P_x^* \alpha HK_0^{\alpha} L_0^{\beta} [\delta(1-\delta)^t R_0]_0^{\gamma}}{r^*} \tag{12}$$

The capital stock desired by the company will be greater the higher the (initial) mining production or the world price of mining exports, and the lower the international interest rate. In turn, the initial production is a direct function of the available stock of mineral resources. If no new mineral resources are discovered, the available stock of resources declines period after period as it is used in the production process, due to which the mining sector's demand for capital will also fall period after period.

But on the other hand, investment cannot instantly increase to close the gap between the desired capital stock and the actual stock. There are adjustment costs that prevent this. A linear version of the flexible accelerator model, from the same family as Hall and Jorgenson's (1967) model, enables formulation of the speed at which companies adjust capital stock to the desired stock over time.

$$K_t = K_{t-1} + \varepsilon(K^o - K_{t-1}) \; ; 0 < \varepsilon < 1. \qquad (13)$$

In this equation, $\varepsilon$ is a parameter of the speed of adjustment, which indicates the extent of the gap between optimal capital and existing capital$(K^o - K_{t-1})$ that the company seeks to close in a given period.

Consequently, investment in the mining industry $(I^m)$ —that is, the change in the capital stock in that industry— is determined by the following equation,

$$I^m = K_t - K_{t-1} = \varepsilon(K^o - K_{t-1}) \qquad (14)$$

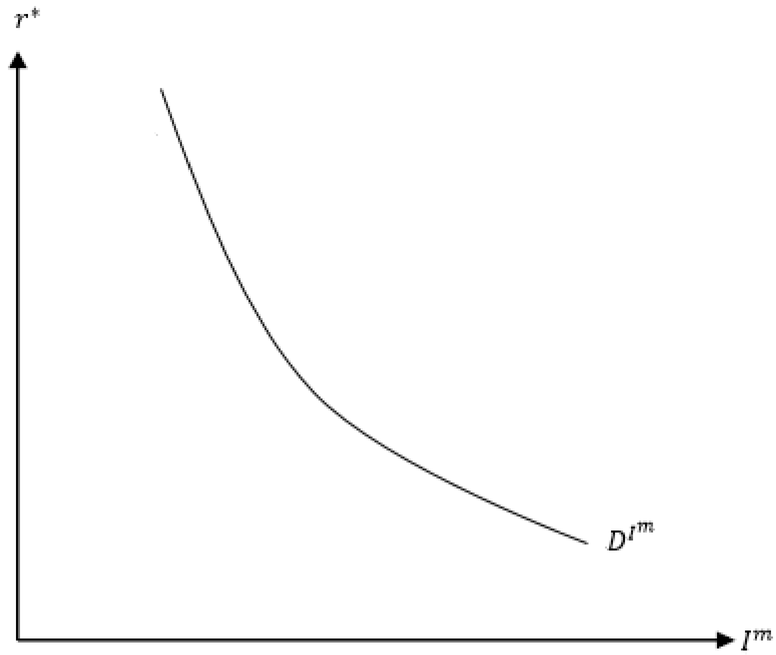
By replacing (12) with (14), we arrive at the equation with the determinants of mining investment, from the demand point of view.

$$I^m = \varepsilon \left[\frac{P_x^* \alpha Y_0}{r^*} - K_{t-1}\right] \qquad (15)$$

Reordering this equation, we arrive at equation (16), which is the mining-investment demand curve, represented by Figure 1.

$$r^* = \frac{\varepsilon P_x^* \alpha Y_0}{I^m + \varepsilon K_{t-1}} \quad (16)$$

Figure 1
Mining investment demand




As summarized in equation (17), the demand for investment in the mining industry is a direct function of the speed of adjustment of the sector's capital stock to its optimal level, the international price of mining exports, and the initial volume of mining production; and an inverse function of the international interest rate and the capital stock from the previous period. As we saw earlier, the initial mining production is a direct function of the available stock of mineral resources, which tends to depletion as it is used in the production process.

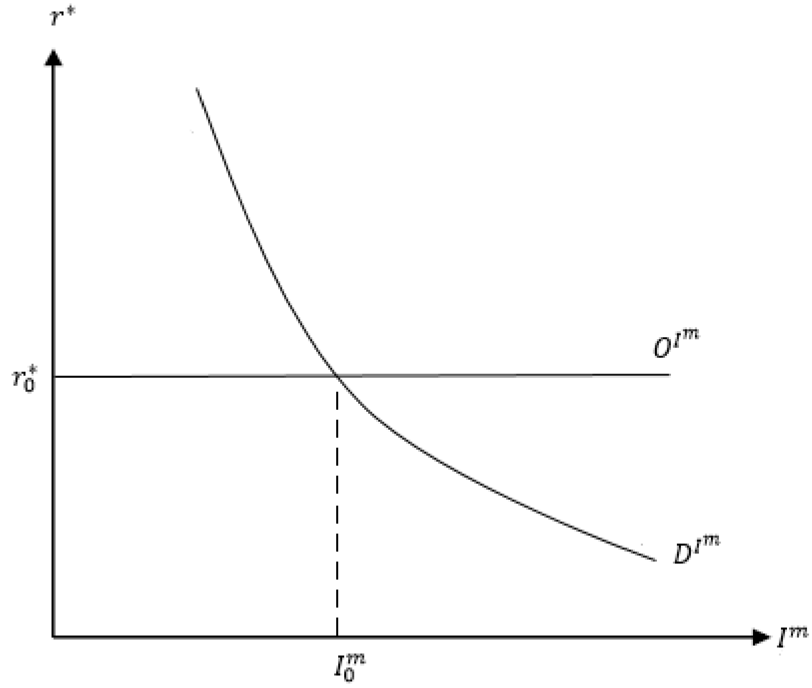
$$I^m = I^m(\varepsilon, P_x^*, Y_0, r^*, K_{t-1}) \quad (17)$$

For this export sector, given the presence of free movement of financial capital, the supply of financing from investments is perfectly elastic to the international interest rate.

$$r^* = r_0^* \tag{18}$$

Thus, the equilibrium in the mining investment market can be represented by Figure 2.

Figure 2
The mining investment market




1.2 Investment in housing

For the non-tradable sector of the economy, we present a housing supply and demand model based on that included in chapter 2.4 of Sorensen and Whitta-Jacobsen (2009). See also chapter 5 of Mendoza (2018).

*Housing supply*

Let us consider the following production function of the housing construction firm.

$$I^V = AX^\beta;\ 0 < \beta < 1 \tag{19}$$

In this expression, $I^V$ is a constructed housing unit, $X$ is a compound production factor (labor and construction materials), $A$ is a constant that represents public infrastructure (roads, motorways, other transportation routes) necessary for the construction of housing[3], and $\beta$ expresses that the production of housing is subject to decreasing returns to scale. To obtain the compound input, companies combine labor and building materials in fixed proportions. Let us assume that the unit cost of the compound input is $C^V$.

If the price of the houses in local currency is $P^V$, the construction firm's profit ($\Pi^V$) is equal to the difference between income from the sale of housing ($P^V I^V$) and the total costs of producing it ($C^V X$). Moreover, taking into account, based on (19), that $X = \left(\frac{I^V}{A}\right)^{1/\beta}$, we obtain the following expression

$$\Pi^V = P^V I^V - C^V X = P^V I^V - C^V \left(\frac{I^V}{A}\right)^{1/\beta} \tag{20}$$

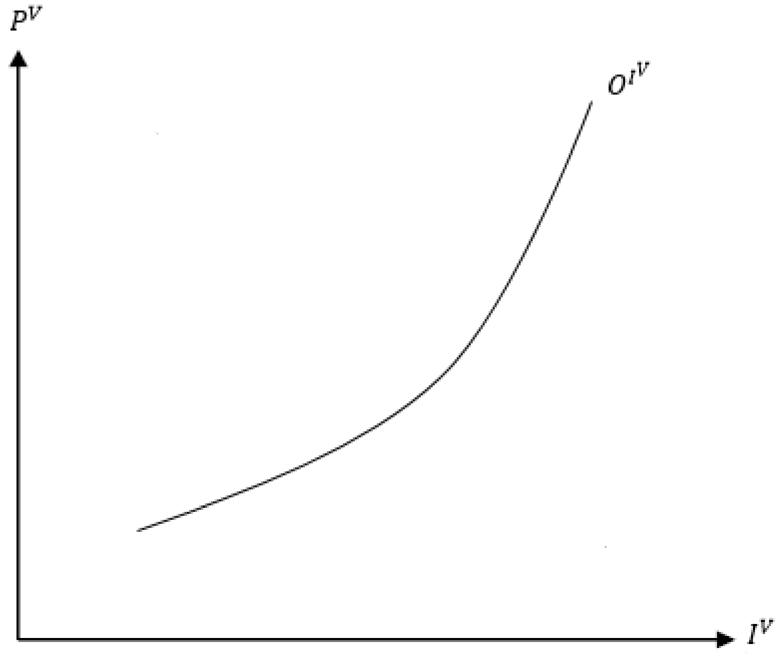
A competitive construction firm will select the level of investment that allows it to maximize its profits. From equation (20), it is inferred that the construction firm maximizes profits when the price of the housing, ($P^V$), equals the marginal cost of producing it ($\frac{\partial C^V X}{\partial I^V}$). That is, when,

$$P^V = \frac{C^V}{\beta A}\left[\frac{I^V}{A}\right]^{(1-\beta)/\beta} \tag{21}$$

This is, also, in perfect competition, the supply curve of the housing construction firm shown in Figure 3.

3 We are also assuming here that that there is complementarity between public and private investment.

Figure 3
Housing investment supply




From this expression, by finding $I^V$, the function showing the determinants of investment in housing is obtained, from the supply side.

$$I^V = k\left[\frac{P^V}{C^V}\right]^{\beta/1-\beta} ; k \equiv \beta^{\beta/(1-\beta)} A^{1/(1-\beta)} \qquad (22)$$

Investment in construction is therefore a direct function of the relative price of houses in terms of the unit cost of production, and of the public infrastructure stock. Note that the relative price $\frac{P^V}{C^V}$, which links the housing market price to the cost of producing it, is similar to Tobin's $q$ which relates the market value or the stock-market value of a capital good with the production cost of that capital good. Our housing construction investment model therefore fits Tobin's $q$ theory.

*Housing demand*

On the demand side, we will assume that there is a typical consumer with a utility function and a budget for purchasing non-durable consumer goods, for paying interest on a mortgage loan, and for the depreciation costs of the housing acquired with the mortgage. Part of consumer income is linked to mining activity[4].

The utility function of these families is of the Cobb-Douglas type, which depends on the housing trend ($I^V$)[5] and the consumption of non-durable goods ($C$).

$$U = (I^V)^n (C)^{1-n};\ 0 < n < 1 \tag{23}$$

To define the consumer's budget constraints, let us suppose there is a representative consumer who applies for a mortgage to acquire a quantity of housing $I^V$ at the unit price $P^V$, and that in each period she spends a fraction of the total value of the housing to pay the mortgage interest $(r)$ and to cover the housing depreciation costs, which is composed of the costs of maintenance and repairs $(\mu)$. The total cost for the consumer of having a house is therefore given by the financial cost (the payment of interest on the debt) and the depreciation of the property; that is, $(r + \mu)P^V I^V$, also known as the house's usage cost. If the consumer has a nominal income $Y^n$ as a result of her labor, to which the mining income is added, which is a fraction of the mining investment, $\epsilon I^m$, does not save, and consumes a quantity$C$ of non-durable goods whose unit price is 1, then her budget constraint is given by,

$$Y^n + \epsilon I^m = C + (r + \mu)P^V I^V \tag{24}$$

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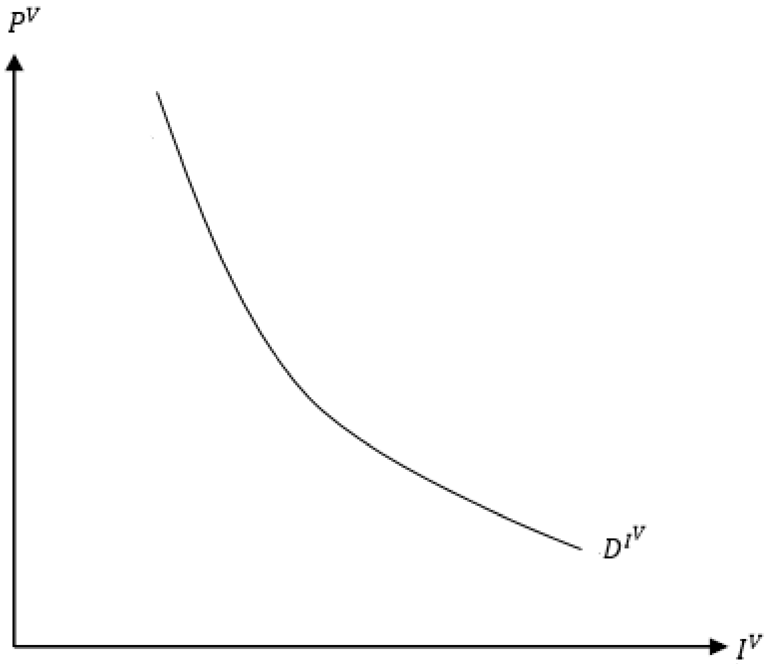
[4] This income is associated with the institutional arrangement in Peru, in which half of the income tax from mining activity is shared out as the *canon minero* among regional governments, municipal governments and public universities.

[5] Strictly speaking, the consumer obtains utility from the housing service, not from the quantity of housing. We are assuming that the housing service is proportional to the quantity of housing.

The consumer seeks to maximize her utility function (23), subject to her budget constraint, equation (24). From this optimization procedure we obtain the consumer's demand for housing, represented by equation (25) and Figure 4.

$$P^V = \frac{n(Y^n + \epsilon I^m)}{(r+\mu)I^V} \tag{25}$$

Figure 4
Housing investment demand




According to expression (25), the relationship between the price and the quantity of housing demanded is inverse, while the relationship between family income and mining investment is direct. Moreover, as the family acquires the housing with a mortgage and as the housing is subject to a depreciation rate, the housing price is also inversely related to the interest rate and the depreciation rate.

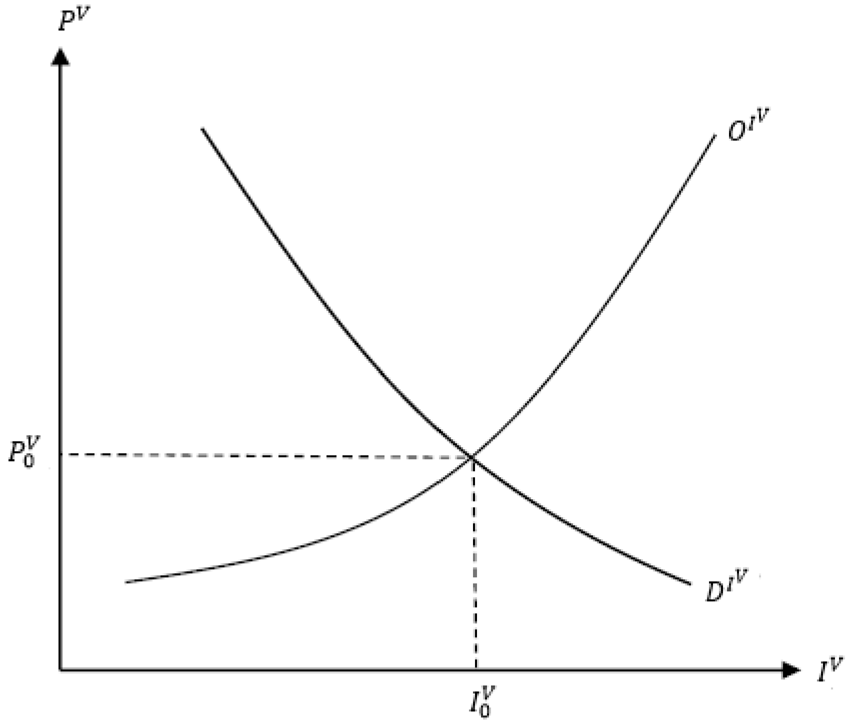
*Determinants of housing investment*

From the housing supply and demand equations —(21) and (25), respectively— we can determine the equilibrium value of the housing volume and price. The equilibrium in the housing market is shown in Figure 5.

$$I^V = A(\beta)^\beta \left[\frac{n(Y^n+\epsilon I^m)}{(r+\mu)C^V}\right]^\beta \quad (26)$$

$$P^V = \frac{(C^V)^\beta}{A(\beta)^\beta}\left[\frac{n(Y^n+\epsilon I^m)}{r+\mu}\right]^{1-\beta} \quad (27)$$

Figure 5
The housing investment market




Consequently, the equation (28) shows that investment in the non-tradable sector of the economy is a direct function of the public infrastructure stock available to the construction industry, consumer income, and mining investment; and an inverse function of the unit cost of housing production, the mortgage interest rate, and the housing depreciation rate.

$$I^V = I^V(A, Y^n, I^m, C^V, r, \mu) \quad (28)$$

## 2. CHANGES IN THE INTERNATIONAL CONTEXT AND DEPLETION OF MINERAL RESOURCES

In this section we will carry out comparative statistical exercises to evaluate the effects that changes in the international economy (the rise in the world price of mining exports and the rise in the international interest rate) and the depletion of the non-renewable natural resource have on investment in mining and the housing sector.

### 2.1 The rise in the international price of mining exports

When the price of mining exports goes up, the value of the marginal product of capital rises to beyond the international interest rate. This disequilibrium presents an opportunity for mining producers to raise the capital stock desired by the company, produce more, and thereby maximize profits.

However, adjustment costs apply. Thus, the desired capital stock is momentarily situated above the capital stock from the previous period. Consequently, as per equation (13), in the following periods the actual capital stock gradually approaches the desired stock until both values are the same. The greater capital stock pushes down the marginal product of capital, and thus equilibrium is restored between the value of the marginal product of capital and the international interest rate. In the process, investment in mining will have increased.

And what effect does the increase in the price of mining exports have on housing investment?

The effect is indirect. A rise in the price of exports, as we have just seen, pushes up mining investment. The increase in mining investment, due to the aforementioned mechanisms, raises the income of consumers who demand housing. In this non-tradable sector of the economy, the higher demand pushes up investment in housing[6].

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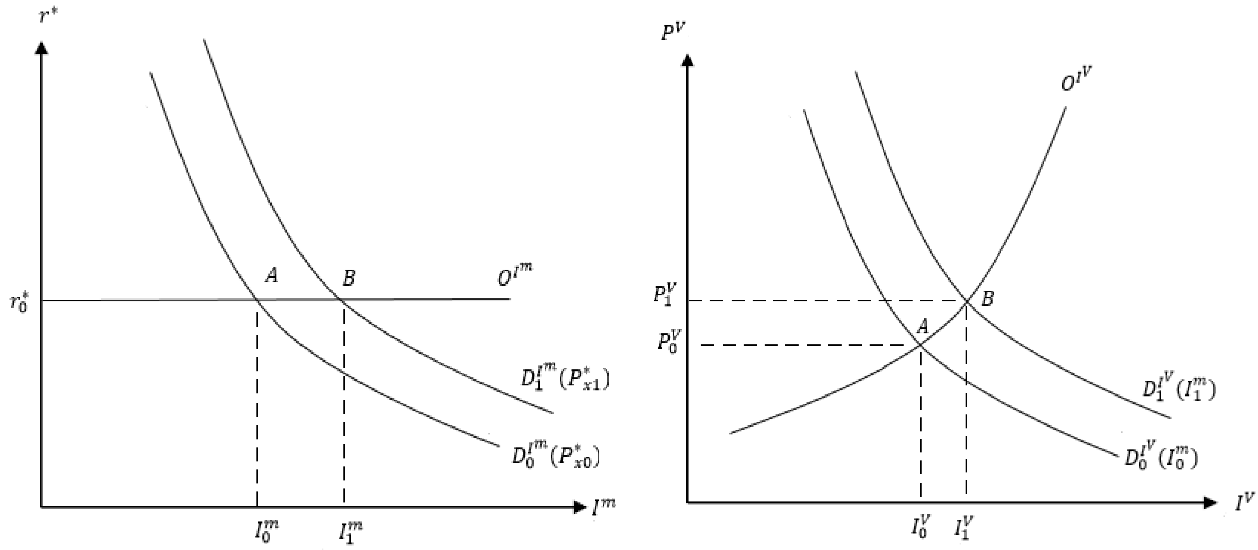
[6] It also raises the price of housing, which is not the focus of our attention here.

Figure 6 shows the effects of the increase in the price of mining exports. In Figure 6.a, there is a rightward shift in the mining-investment demand curve, due to the rise in the world export price; while Figure 6.b shows a rightward shift in the investment demand curve in the housing sector, explained by greater investment in mining.

Figure 6
The effects of the increase in the price of exports

Figure 6.a Figure 6.b




The mathematical response to the effect that the higher export price has on mining investment is obtained from equation (15).

$$dI^m = \varepsilon \frac{\alpha Y_0}{r^*} dP_x^* > 0$$

The effects on investment in the housing sector are obtained from equation (26) and the previous result.

$$dI^V = A(\beta)^\beta \left[\frac{\epsilon dI^m}{(r+\mu)C^V}\right]^\beta = A(\beta)^\beta \left[\frac{\epsilon\varepsilon \frac{\alpha Y_0}{r^*} dP_x^*}{(r+\mu)C^V}\right]^\beta > 0$$

## 2.2 The rise in the international interest rate

When the international interest rate goes up, the value of the marginal product of capital stays below the new international interest rate. This situation prompts mining producers to reduce the capital stock desired by the company to reduce mining production and keep on maximizing profits under the new international conditions.

Since there are adjustment costs, the desired capital stock momentarily drops below the capital stock from the previous period. In the following periods the actual capital stock gradually approaches the desired stock until both values are the same. The lower capital stock pushes up the marginal product of capital, and thus equality is restored between the value of the marginal product and the international interest rate. Investment in mining will have decreased.

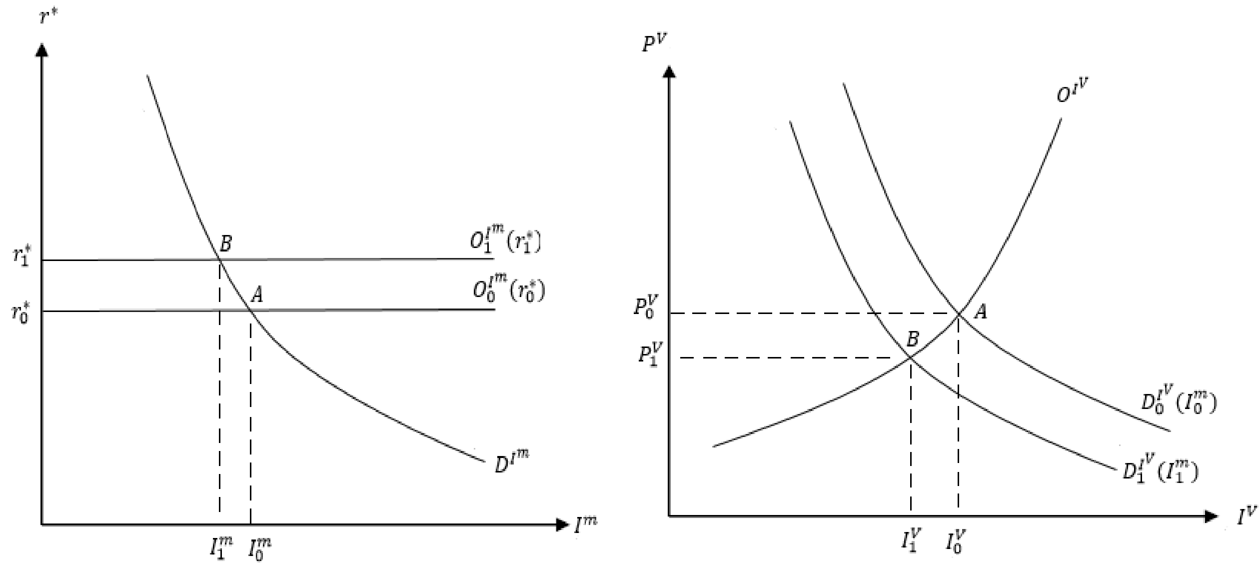
And what effect does the rise in the international interest rate have on housing investment?

As in the previous case, the effect is indirect. The rise in the international interest rate causes mining investment to fall. The lower mining investment reduces the income from consumers who demand housing. The lower demand pushes down investment in housing.

Figure 7 represents the effects of the rise in the international interest rate. Figure 7.a records the effect of the rise in the international rate on mining investment as an upward shift in the international-financing supply curve. Figure 7.b expresses the effect on investment in the housing sector as a leftward shift in demand for housing investment, due to lower investment in mining.

Figure 7
The effects of the increase in the international interest rate

Figure 7.a Figure 7.b




In mathematical terms, the effects of the higher international interest rate on investment in mining and housing is given by,

$$dI^m = -\varepsilon \frac{P_x^* \alpha Y_0}{(r^*)^2} dr^* < 0$$

$$dI^V = A(\beta)^\beta \left[\frac{\epsilon dI^m}{(r+\mu)C^V}\right]^\beta = -A(\beta)^\beta \left[\frac{\epsilon\varepsilon \frac{P_x^* \alpha Y_0}{(r^*)^2} dr^*}{(r+\mu)C^V}\right]^\beta < 0$$

## 2.3 The effects of the passage of time

What happens if time passes and no new mines are discovered?

For this exercise, it is important to recall the equation of mining production in the initial situation, which is affected by the rule for extraction of the non-renewable natural resource in which mining production tends to zero ($Y_0 \to 0$) as time tends to infinity ($t \to \infty$).

$$Y_0 = HK_0^\alpha L_0^\beta M_0^\gamma = HK_0^\alpha L_0^\beta [\delta(1-\delta)^t R_0]_0^\gamma$$

Thus, the passage of time, which we express as an increase in $t$, causes a decrease in $Y_0$. In turn, the initial fall in mining production causes a reduction in the marginal product of capital in mining. As a result, the value of the marginal product of capital is situated below the international interest rate, which causes a reduction in the capital stock desired by the mining company.

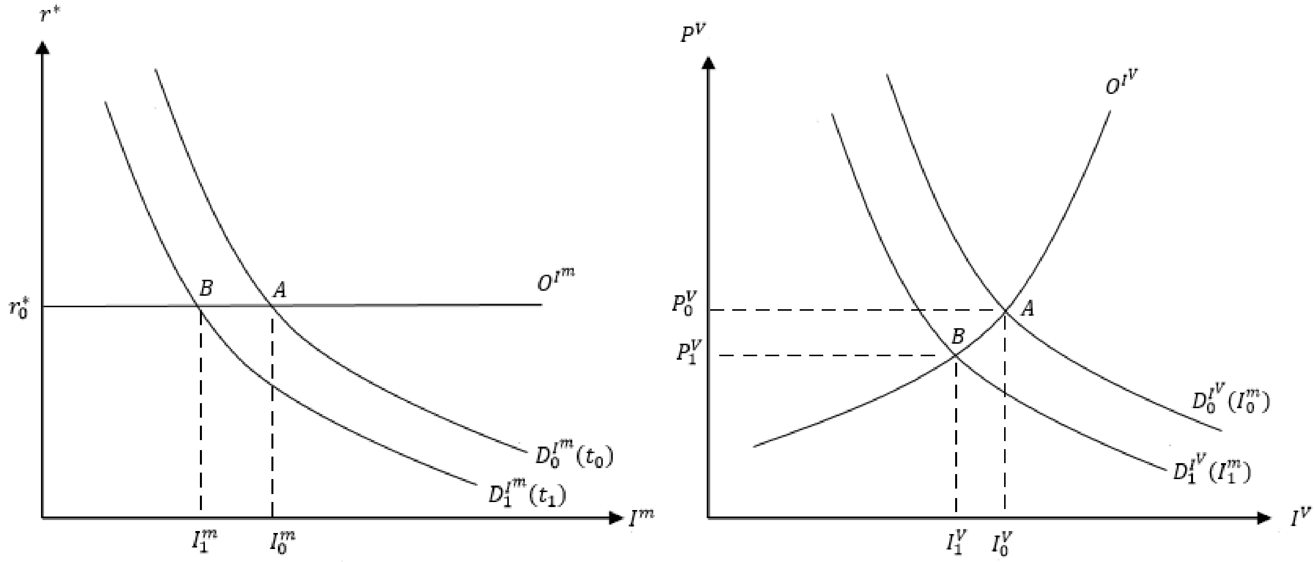
As the capital adjustment is not immediate, the desired capital stock momentarily drops below the capital stock from the previous period. In the following periods the actual capital stock will fall and gradually approach the desired stock until both values are the same. The lower capital stock pushes up the marginal product of capital, and thus equilibrium is restored between the value of the marginal product and the international interest rate. Investment in mining will have decreased.

The effect of the passage of time on investment in housing is also indirect. The fall in the stock of the non-renewable resource causes mining investment to drop. The lower mining investment reduces the income from consumers who demand housing. The lower demand pushes down investment in housing.

Figure 8.a represents the passage of time as a leftward shift in the mining-investment demand curve, due to the rise in $t$, while Figure 8.b shows the leftward shift in the housing-investment demand curve, due to mining investment.

Figure 8
The effects of the passage of time on mining investment

Figure 8.a Figure 8.b




In mathematical terms, the effect of the passage of time on mining investment and investment in the housing sector is given by,

$$dI^m = \varepsilon \frac{P_x^* \alpha}{r^*} dY_0 = \varepsilon \frac{P_x^* \alpha}{r^*} \left[ \ln(1-\delta)[\delta(1-\delta)^t R_0]_0^\gamma \gamma H K_0^\alpha L_0^\beta \right] dt < 0$$

$$dI^V = A(\beta)^\beta \left[ \frac{\epsilon dI^m}{(r+\mu)C^V} \right]^\beta = A(\beta)^\beta \left[ \frac{\epsilon \varepsilon \frac{P_x^* \alpha}{r^*} \left[ \ln(1-\delta)[\delta(1-\delta)^t R_0]_0^\gamma \gamma H K_0^\alpha L_0^\beta \right] dt}{(r+\mu)C^V} \right]^\beta < 0$$

## 3. CONCLUSIONS

We have presented a model to identify the determinants of investment in the mining and housing sectors.

The model shows the strong dependence of investment in mining and construction on international conditions. A favorable international environment, due to a rise in the price in mining exports or a fall in the international interest rate, drives investment in mining and the housing sector.

Moreover, according to the model, the existence of a non-renewable mining production factor means that if no new mines are discovered over time, then investment in mining and in housing must decrease.

Finally, in the model there is asymmetry between the two types of investment. Mining investment affects, but is not affected by, what goes on in the housing construction sector.

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