



**A Preliminary Analysis of The Economic Behavior Underlying the Industrial  
Symbiosis Phenomenon**

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## *Abstract*

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### **A Preliminary Analysis Of The Economic Behavior Underlying The Industrial Symbiosis Phenomenon**

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The industrial symbiosis phenomenon represents the possibility of integrating economic gains and the reduction of environmental damage by providing a framework in which the exchange synergies within an industrial cluster are exploited. There are only a few successful examples in reality, for reasons that will be discussed in the next sections. The objective of this paper is to identify the mechanism behind the under-provision of the exchanges that characterize the Industrial Symbiosis phenomenon and determine whether regulation could and should play a role in fostering it, from a Micro-Economics approach. The analysis results in the identification of a specific scenario in which a market failure justifies the government intervention that aims to increase welfare by exploiting the optimal level of Industrial Symbiosis.



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## Chapter 1

# Introduction and Literature review

### 1.1 Introduction

Industrial clusters are agglomerations of firms within a specific geographical range. In the economics literature, they are well known for providing positive externalities, such as economies of scale due to knowledge spillovers, generally for clusters with companies that belong to the same or similar industries. In this paper, I will take a different approach to analyse the positive externalities associated with industrial clusters, for those who are composed of firms that belong to different industries.

Some cases of industrial cluster have proven to be associated with substantial economic and environmental benefits, which are derived from material, energy, and knowledge exchanges between firms in an industrial cluster (for industrial clusters composed by firms that belong to completely different industries). This phenomenon has been named **industrial symbiosis** by the literature in industrial ecology<sup>1</sup> in the industry). , after the symbiosis phenomenon in biology.

There are certain levels of organization in industrial clusters according to the literature. In general, these are divided into SO (Self-organized IS) and CP (Central planning IS), which entails all the possible ways of emergence (Chertow, 2007).

For several reasons there are only a few of such cases in reality. The literature has defined some factors that might cause this. I will use some of this insight to design a simple model that could allow me to analyse the Economic incentives as well as the market failures that could explain the above-mentioned under-provision, in a very simple model. Often in reality, market structures don't meet the perfect competition assumptions (e.g. have a certain degree of market power), which gives incentives for firms to disclose information, that could give competitors an advantage over them. This general disclosure of information on production and cost structures is one of the main factors preventing optimal by-product<sup>2</sup> exchanges from taking place within industrial clusters, given that these can only occur once synergies<sup>3</sup> (in terms of exchange possibilities) have been identified. However, this paper does not explore the asymmetries of information between the companies in an industrial cluster.

Next, I will analyse some exceptional cases in which several factors, mainly institutional, made Industrial symbiosis (from now on IS) possible. Some valuable insights on IS formation will be gathered by analyzing some of the factors that have been identified in the literature.

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<sup>1</sup>Field that intends to increase the level of circularity , which is the volume of reduced waste as a result of by-product exchange (Leigh, M., Li, X. (2015))

<sup>2</sup>By-product: an incidental or secondary product made in the manufacture or synthesis of something else.

<sup>3</sup>Synergies: the interaction or cooperation of two or more organizations, substances, or other agents to produce a combined effect greater than the sum of their separate effects.

Then the main purpose of this paper is to use this insights altogether with Microeconomics theory in order to identify the mechanism behind the under-provision of the IS phenomenon and determine whether regulation could and should play a role in fostering it.

Then the following question arises: *To which extent is government intervention desirable or necessary to foster the level of industrial symbiosis in industrial agglomerations?*

## 1.2 Literature review

In this literature review, two industrial clusters will be analyzed which, although operating under the same principles of waste exchange, conceived the industrial symbiosis differently. Marian R. Chertow (2007) proposes that to understand the emergence of industrial symbiosis, we must consider the two models. On the one hand, there is the self-organization model carried out by industries in free-market conditions. In this model, interest in economic benefits such as cost reduction and the guarantee of scarce resources in the long term allow for symbiosis. On the other hand, there is a Central planning organization model, which is conceived by government entities. To begin with, let's consider the self-organization model.

### 1.2.1 Self-organized

This type of industrial symbiosis occurs thanks to the organization and identification of synergies by local companies. Proximity is one of the fundamental conditions for the formation of complex industrial ecosystems like the one in Kalundborg, Denmark. "The key to industrial symbiosis is collaboration and the synergistic possibilities provided by proximity" (Chertow, 2000, p. 216). Chertow (2007) highlights the possibilities of industrial symbiosis by classifying them into three types of synergies:

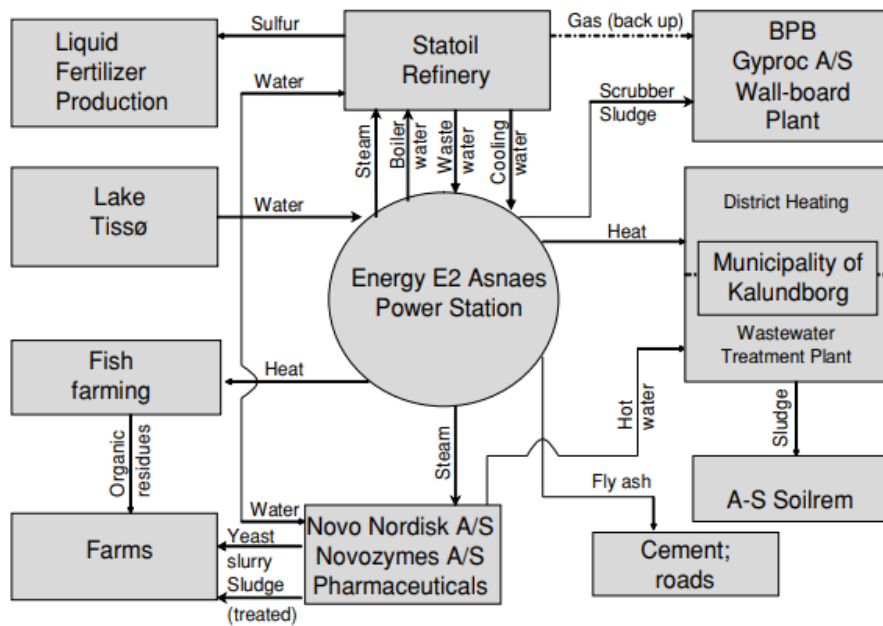
1. Reuse of by-products: the exchange of company-specific materials between two or more parties for use as substitutes for commercial products or raw materials.<sup>4</sup>
2. Utilities/infrastructure sharing: the joint use and management of commonly used resources, such as energy, water, and wastewater.
3. Joint provision of services: meeting the common needs of all companies for ancillary activities, such as fire suppression, transportation, and food provision.

The most representative eco-industrial park of the free market model is the one in Kalundborg, Denmark, where various types of exchanges that take place are between local firms that were not purposely located nearby.

"Firstly, we note that rather than being the result of planning a multi-agent process..., the Kalundborg symbiosis emerges from self-organization initiated in the private sector to achieve the above-mentioned achievements, such as reducing costs, the increase in profit, the expansion of the industry and the long-term insurance of water and energy resources."(Chertow, 2000, p. 320).

The Kalundborg eco-industrial park was originally made up of an oil refinery, a power station, a pharmaceutical plant, and the city of Kalundborg (agents that

<sup>4</sup>This paper will focus on this type of synergies



**Figure 3** Industrial symbiosis of Kalundborg, Denmark.

FIGURE 1.1: Source: Chertow, M. R. (2007). "Uncovering" industrial symbiosis. *Journal of Industrial Ecology*, 11(1), 11-30.

make up the internal and external levels of the industrial symbiosis). The industrial symbiosis was the result of the effort of a committee of managers, called the environmental committee, to guarantee long-term access to water resources. In the midst of the proposals for the guarantee of water resources, the companies managed to identify some synergies, which they later took advantage of giving rise to the industrial symbiosis. In the symbiotic process, these agents share water resources, waste, steam electricity, in addition to exchanging a wide variety of wastes that are raw materials for other processes. This leads to a large increase in environmental and economic efficiency, as well as benefits for companies, such as the information diffusion. The social impact starts from a better allocation of resources and an improvement in market failure with a reduction in information asymmetries.

It would be ideal if the invisible hand of the free market allowed the creation of eco-industrial parks, however, there are great barriers to reaching an industrial symbiosis like that of Kalundborg. To begin with, the industries in the world are under complex scenarios, which make the industrial symbiosis unattractive in terms of risk, finances and capital mobility, as well as the lack of trust between companies that exclusively seek to maximize their own profit. It is for this reason that in most cases the intervention is necessary, either from the State or from NGOs, that pose a series of optimal conditions for the establishment and implementation of the industrial symbiosis.

In the case of Kalundborg, the institutions that made this possible were "Environmental Club" and "The Symbiosis Institut", made up of stakeholders. Chertow (2000) recognizes a series of tools that can be used by institutions to promote industrial symbiosis through identification of synergies and policy. These include the "Input-Output Matching" : FaST (Facility Synergy Tool), DIET (Designing Industrial Ecosystems Tool) and REaLiTy (Regulatory, Economic, and Logistics Tool), and

the “Material Budgeting”. The former consist of models that allow possible synergies in a group of companies to be identified, through an analysis of production processes. Those of “Material Budgeting” consist of drawing a map of the material flows in a determined system (cluster).<sup>5</sup>

Governments can find great opportunities for welfare development in the industrial symbiosis. (Chertow, 2007, p. 18). exposes some of these development benefits: “(1) revitalize urban and rural sites; (2) Promote job creation (China case discussed below); (3) And promoting sustainable development. ”(Chertow, 2007, p. 18).

In this sense, the intervention may be aimed at creating policies and institutions that promote symbiosis between industries through these tools. (Chertow, 2007, p. 24) proposes the following ideas for public policy<sup>6</sup> to promote IS:

- Reveal symbiotic nuclei (kernels) of cooperative activity that are still hidden.
- Assist the symbiotic kernels that are in formation.
- Provide incentives to catalyze new symbiotic nuclei by identifying “precursors of symbiosis”.

### 1.2.2 Central planning

China exposes a good example of the application of industrial symbiosis generated from central planning. A case study is from the Guitang Group (GG) in Guangxi Zhuang Province (Zhu, Lowe, Wei, Barnes, 2007), which currently consists of 5 factories operating within the complex: a mill, a cement factory, an alcohol still, a paper mill, and a product mill. fertilizers.

The internal symbiosis focuses on the reuse of waste from industries. These five factories use bagasse (the part of the sugarcane left over after cutting) at some point in one of their production processes. Reusing waste reduces production costs (part of the raw materials are no longer cost) and also there is no payment to get rid of the waste from the bagasse. **In the case of central planning, internal incentives are easily adjusted (access to raw materials, problem raised in the introduction) since they are all part of a conglomerate.** “The internal symbiosis of GG’s operations has resulted in increased efficiency and productivity per unit produced.” (Zhu, Lowe, Wei, Barnes, 2007, p. 35).

Therefore, this process improves efficiency, lowers the final price (making it more competitive), especially in products that do not have high added value.

## 1.3 Synthesis

Having exposed both ends of the industrial symbiosis, one common characteristic is found: for the industrial symbiosis to occur, it is necessary to establish a framework of incentives and conditions that favor all the agents involved. In this sense, sufficient guarantees must be provided to reduce the risk and difficulties that companies encounter when creating an ecosystem in which there is cooperation and exploitation of synergies. Also, a legal framework must be provided in which compliance with regulations goes hand in hand with sustainable development policies, so that companies are not only incentivized by economic benefits but also by obligations to

<sup>5</sup>This are examples of the identification methods I talk about in chapter 3.

<sup>6</sup>the policies proposed in Chapter 4 are highly influenced by this

the state. This is to establish a midpoint in the formation of industrial symbiosis, with the aim of making industrial ecosystems more feasible.

The difference between the two approaches lies in how business success is achieved. In other words, under a centralized perspective, the industries within the symbiosis never went through the "market test" (Porter, 2008, p. 225), which means that at an early stage it did not face competition or the challenges of market. Although in the case of China it was not a problem, one could speak of a ramification of a single sugar industry that saw the opportunity to find benefits by taking advantage of its waste. On the contrary, in the United States where the Presidential Council for Sustainable Development (USPCSD) tried to encourage the creation of eco-industrial parks, from a centralized perspective, it showed a resounding failure. Chertow (2007) shows that it is not enough that from the beginning the reuse of waste is proposed, but that the companies individually go through the "market test" and subsequently find greater benefits in the industrial symbiosis.



## Chapter 2

# The Model

This model employs a micro-economic approach to analyse the behaviour of two firms that share an exchange synergy in common.

### 2.1 Environment description

In this simple model, there are 2 firms in a industrial cluster: Firm i and Firm j. Both firms sell their main product in perfectly competitive markets, which makes them price takers (adopting  $p_i$  and  $p_j$ , respectively).

Firm i produces a product  $q_i = A_i(k_i)^\beta$  (Cobb-Douglas form), where  $k_i$  is the only input required. Furthermore, a By-product  $B_i = \phi_i q_i$  is derived from the production process, where  $\phi_i \in [0, 1]$ .

It is assumed that firms have one exchange synergy in common. That is,  $B_i$  can either become contaminating waste  $w_i = \phi q_i - k_{j,i}$ , which is taxed at a rate  $\tau_i$ , or an input for Firm j sold at price  $P_{k,j,i}$ . There is a cost associated with every unit of by-product sold (transportation and transformation process cost)  $C_{TT} = c * k_{j,i}$ .

As described before, Firm j produces a product  $q_j = A_j(k_j)^\alpha$  and no By-products. Firm j can buy the input required  $k_j$  from an external market at a given price  $P_{k,j,m}$  or from Firm i (as mentioned before). These two options have a perfect substitution. Therefore, Firm j will demand the one with the lowest price. It is assumed that when the prices are equal, Firm j will prefer Firm i's by-product.

There is a capacity constraint, nonetheless, and it implies that the amount of input that Firm j can obtain from Firm i is bounded by the amount of By-product  $B_i$  produced by Firm i.

### 2.2 Sequential Stages in the model

1. Firm i sets the level of output  $q_i^*$ .
2. Firm i determines the price  $P_{k,j,i}^*$  at which every unit of Firm j's input  $k_{j,i}$  will be offered.
3. Firm j decides on the amount of input  $k_{j,i}^*$  that it will demand from Firm i and the external market option  $k_{j,m}^*$ .

### 2.3 Equilibrium in the industrial cluster

In order to arrive to the equilibrium in the model, backward induction must be performed.

The steps that will be taken in the backward induction process are as follows:

1. Find firm j's optimal demand for input  $k_j$ .
2. Find optimal input price  $P_{k,j,i}^*$  (as defined by Firm i).
3. Find Firm i actual optimal production level  $q_i^*$ .

Lets dive into Firm i's mind.

### 2.3.1 First step:

By this stage of the model (3rd stage), firm i has decided on the amount of by-product that it produces and the price  $P_{k,j,i}$ , now Firm i wants to know the best response from Firm j.

Now it is assumed that Firm i set a price lower than the external option  $P_{k,j,i} \leq P_{k,j,m}$  given that if it sets higher price, Firm j won't buy any part of the by-product. Then Firm j's optimization problem is as follows:

$$\text{Max } \pi_j = p_j q_j - C_{kj}$$

s.t.

$$C_{kj} = \begin{cases} P_{k,j,i} k_j & , \text{ if } k_j \leq B_i \\ P_{k,j,i} B_i + P_{k,j,m} (k_j - B_i) & , \text{ if } k_j > B_i \end{cases}$$

This optimization problem must be analysed for each piece of the cost function.

The input demand that maximizes the profit function for the interval defined by  $k_j < B_i$  (Case 1), yields:

$$k_{j,i}^* = \left( \frac{\alpha p_j A_j}{P_{k,j,i}} \right)^{\frac{1}{1-\alpha}} ; k_{j,m}^* = 0 \quad (2.1)$$

For the case in which the cost is defined by the interval  $k_j > B_i$  (Case 2), the optimal input yields:

$$k_{j,i}^* = B_i ; k_{j,m}^* = B_i - \left( \frac{\alpha p_j A_j}{P_{k,j,m}} \right)^{\frac{1}{1-\alpha}}$$

Then there is  $k_j = B_i$  (Case 3), which yields:

$$k_{j,i}^* = B_i ; k_{j,m}^* = 0$$

The Case 1 and 3 equilibrium cannot coexist with that of Case 2 given that they cannot be consistent with their respective interval condition (e.g.  $k_j \leq B_i$ ) at the same time given the assumption that  $P_{k,j,i} \leq P_{k,j,m}$ :

If Case 2 is consistent:

$$B_i < \left( \frac{\alpha p_j A_j}{P_{k,j,m}} \right)^{\frac{1}{1-\alpha}} \leq \left( \frac{\alpha p_j A_j}{P_{k,j,i}} \right)^{\frac{1}{1-\alpha}}$$

Then, it cannot be true that Case 1 is consistent.

$$k_{j,i}^* = \left( \frac{\alpha p_j A_j}{P_{k,j,i}} \right)^{\frac{1}{1-\alpha}} < B_i \quad (2.2)$$

And viceversa.

Even when the case 2 and 3 lead to  $k_{j,i}^* = B_i$ , they differ in the sense that the equilibrium in case 3 is unstable. A minor increase in price  $P_{k,j,i}$  will lead to the lower demand for  $k_{j,i}$ . This is explained by the form of the cost function. Cases 1 and 3 are determined under the interval  $k_j \leq B_i$  and therefore the price will always represent a factor that influences the demand of input From firm j. Whereas in Case 2, changes in  $P_{k,j,i}$  will not lead to changes in  $k_{j,i}$ , as the cost is partly fixed.

### 2.3.2 Second step

Firm i incorporates the information from step 2 (for each case) into its own optimization problem to find the optimal price  $P_{k,j,i}^*$ . I will assume that exterior market prices for input  $P_{k,j,m}$  are very high, for the sake of simplicity.

#### For Case 1

it yields the following:

$$\begin{aligned} \max_{P_{k,j,i}} \quad & \tau_i k_{j,i}^* + k_{j,i}^* P_{k,j,i} - C_{TT}(k_{j,i}^*) \\ \text{s.t.} \quad & k_{j,i}^* = \left( \frac{\alpha p_j A_j}{P_{k,j,i}} \right)^{\frac{1}{1-\alpha}} \end{aligned}$$

The solution after rearranging the first order conditions yields,

$$P_{k,j,i}^* = \frac{c - \tau_i}{\alpha} \quad (2.3)$$

The optimal price depends on the marginal cost  $c - \tau_i$  and the parameter for output elasticity  $\alpha$ . This implies that a higher sensitivity of the output  $q_i$  upon changes in  $k_i$  will lead to lower price for this input.

$$k_{j,i}^* = \left( \frac{\alpha^2 p_j A_j}{c - \tau_i} \right)^{\frac{1}{1-\alpha}}$$

This monopoly price must be consistent with the condition

As the price decreases,  $k_{j,i}$  gets closer to  $B_i$ . Using the condition For case 2 the limit price that leads to  $k_{j,i}^* = B_i$  can be derived:

$$P_{k,j,i}^* = \left[ \frac{(\alpha p_j A_j)^{\frac{1}{1-\alpha}}}{B_i} \right]^{\frac{1}{1-\alpha}}$$

As mentioned before, for Case 3 a minor increase in the price will represent a lower demand. Therefore, the monopoly price ( derived before) will maximize the profits as it is higher than the top bound price (Maximizes higher revenues). For that reason, the solution for Case 1 and 3 boils down to the monopoly price. That is having assumed  $P_{k,j,m}$  is higher. Then the solution remains interior.

The policy implications will be discussed in the next section. Now I will analyse the solution price for Case 2.

#### For Case 2

the input takes the form  $k_{j,i} = B_i$ .

This leads to the corner solution  $P_{k,j,i} = P_{k,j,m}$ , given that Firm will demand  $B_i$  regardless of the price as long as it is lower or equal to the alternative option  $P_{k,j,m}$ . A lower price will reduce the revenues and a higher price will make them 0.

### 2.3.3 Third step

Now Firm i determines  $q_i$  by solving the maximization problem for the each case.

#### Case 1 and 3

In this cases, the decision for  $q_i^*$  will not be influenced by the amount of by-product sold to Firm j, then the equilibrium quantities is derived from the following optimization problem:

$$\text{Max } \pi_i = p_i q_i(k_i) - k_i P_{ki} - \tau_i B_i$$

The optimality condition for firm i, which sells its product in a perfectly competitive market is  $p_i = MC_i$ , where the marginal cost  $MC_i$  is:

$$MC_i = \frac{P_{ki} k_i^{1-\beta}}{\beta A_i} + \phi_i \tau_i \quad (2.4)$$

Which yields,

$$k_i^* = \left( \frac{\beta A_i (p_i - \tau_i \phi_i)}{P_{ki}} \right)^{\frac{1}{1-\beta}}$$

$$q_i^* = A_i \left( \frac{\beta A_i (p_i - \tau_i \phi_i)}{P_{ki}} \right)^{\frac{\beta}{1-\beta}}$$

$$\bar{B}_i = \phi A_i^{\frac{1}{1-\beta}} \left( \frac{\beta (p_i - \tau_i \phi_i)}{P_{ki}} \right)^{\frac{\beta}{1-\beta}}$$

#### Case 2

Replacing  $P_{k,j,i} = P_{k,j,m}$  and  $k_{j,i} = B_i$ , Firm i solves:

$$\text{Max } \pi_i = p_i q_i(k_i) - k_i P_{ki} - \tau_i [B_i - k_{j,i}^*] + P_{k,j,i}^* k_{j,i}^* - C_{TT}(k_{j,i}^*)$$

Note that for this case there is no waste, and thus the tax represents no cost in the profit function. Then the Marginal cost is as follows:

$$MC_i = \frac{P_{ki} (k_i)^{1-\beta}}{\beta A_i} - P_{k,j,m} + c \quad (2.5)$$

Then the condition for the profit maximization in perfect competition  $p_i = MC_i$  yields:

$$k_i^* = \left( \frac{\beta A_i (p_i + P_{k,j,m} - c)}{P_{ki}} \right)^{\frac{1}{1-\beta}}$$

$$q_i^* = A_i \left( \frac{\beta A_i (p_i + P_{k,j,m} - c)}{P_{ki}} \right)^{\frac{\beta}{1-\beta}}$$

$$B_i = \phi A_i^{\frac{1}{1-\beta}} \left( \frac{\beta((p_i + P_{k,j,m} - c))}{P_{ki}} \right)^{\frac{\beta}{1-\beta}}$$

## 2.4 Government intervention

### 2.4.1 For Case 3 and 1

The monopoly price (equation 2.2) is above the marginal costs

$$P_{k,j,i}^* = \frac{c - \tau_i}{\alpha} > MC = c - \tau_i$$

leading to a low demand of input and a high amount of contaminating waste (relative to the social optimum). This could justify the intervention of the regulating authorities, given that a positive externality (contamination reduction) is not being fully internalized. However increasing the tax rate will also reduce the production of good  $q_i$ , thus decreasing consumer surplus.

Therefore, in order to find the ideal level of optimal tax it would be necessary to assess the impact on Consumer surplus, producer surplus and perhaps social utility from a reduction in contaminating waste. This analysis is unfortunately out of the scope in this model, since the aggregate utility (which are required to determine the consumer surplus) function are taken as given (they are exogenous).

### 2.4.2 For Case 2

When comparing the marginal cost of firm  $i$  in Case (1&3) and that of Case 2 (equations 2.3 and 2.4 respectively) it can be noticed that if  $c - P_{k,j,m} < t_i \phi_i$  holds, then the Marginal cost of firm  $i$  is deflated by the price charged to the by-product as well as the quantities produced in equilibrium. Then, the government intervention is justified, since this is affecting the normal operation of the market by reducing consumer surplus. The competition authorities would formulate policy that aims to increase the quantities produced by Firm  $i$ . The tax rate, however, is not a feasible instrument policy anymore as mentioned before. Then other policy options such a production quota should be considered. Considering the potential policies and their implications is out of scope for this paper, given that full circularity is achieved (all the waste is being reused).



## Chapter 3

# Conclusion

In the literature review it was arrived to the conclusion that even though there are great benefits, for both firms and the society overall, derived from the Industrial Symbiosis exchanges, it would take some level of government intervention to guarantee the existence of the conditions that allow to exploit its full potential. Similarly, the model analysed in this paper lead to the conclusion that under a specific context in which policy intervention (aimed at fostering the exchanges that characterise industrial symbiosis) is justified. In the model, the interaction between two firms with an exchange synergy in common leads to market imperfections in two scenarios. In one of the scenarios, the high prices of the external source of input and the set of specific firm parameters of the receiving firm, grants monopoly power to the firm that produces the by-product. This monopoly power leads to under-provision (with the perfect market as a benchmark) of the receiving firm's input (IS exchange), thus generating higher levels of contamination (lower circularity). For this scenario, adjusting the tax rate is a feasible policy. However, further considerations have to be made in order to find the optimal policy. As for the second scenario that leads to a market failure, intervention is only aimed at increasing the consumer surplus, given that there is full circularity (all the by-product is being reused) and therefore is out for the scope of this paper.

In synthesis, this paper proves that the Industrial symbiosis phenomenon could be worth of attention in the Economics literature. This paper encourages further research in the topic, perhaps with a model that explores the interactions of firms (within an industrial cluster) that face uncertainty in the existence of the synergies in common.



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