Regional Agglomeration of Major Risky Activities and Environmental Policies

Marie-Françoise Calmette*
ARQADE, Toulouse School of Economics
Associated researcher IDEI
Université des Sciences Sociales, 31000 Toulouse France

Isabelle Péchoux
ARQADE, Toulouse School of Economics
LEERNA
Université des Sciences Sociales, 31000 Toulouse France

The recent AZF industrial catastrophe in Toulouse[1] and its long lasting consequences have shown, once again, the importance of good management of industrial/environmental risks.

Several major industrial accidents have occurred world-wide; among others, Seveso became a symbol: In July 1976, the explosion of a chemical reactor of the company Icmesa, located in Lombardy (Italy) near the town of Seveso caused a throwing out of dioxins in the atmosphere. The European Community's institutional response to the Seveso disaster was given by Council Directive 82/501/EEC *on the major accident hazards of certain industrial activities*, the so-called Seveso Directive.[2] Both amendments to that directive,[3] after the Bhopal catastrophe (1984), included recommendations on the storage of dangerous substances. In

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* Corresponding author : Calmette Marie-Françoise, ARQADE, Manufacture des tabacs, Aile J-J Laffont, 21 Allée de Brienne, 31000 Toulouse France.

1. On the 21st September 2001, a storage of ammonitrate (around 300 tons) blew up on the AZF site of the Grande Paroisse company (Total-Fina-Elf). This explosion was worsened by the fact that, at a distance of 500 metres from AZF, the NSPE (National Society of Powders and Explosives) produced the motor fuel used by the Ariane rocket which requires very dangerous substances. Today, the exact reason for the explosion is still unknown.
2. O.J. N° L 230 of 5th August 1982.
3. Directive 87/216/EEC, O.J. N°L 85 of 28 March 1987 and Directive 88/610/EEC, O.J. N°L 336 of 7 December 1988.

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particular, the new concept of 'land-use planning' was introduced, implying that policies should ensure that appropriate distances between risky *establishments* and *residential areas* are guaranteed.

Oddly enough, the directive is not concerned with the agglomeration of such establishments even though its seems evident that a major industrial catastrophe is more likely to occur when there is a concentration of risky activities. In this paper, we assume that agglomeration of risky activities increases the population's vulnerability to high risk of considerable damage compared to its vulnerability to multiple small risks associated with dispersed activities. This assumption can be justified on factual grounds: several arguments suggest that the probability that an accident occurs in a place where many risky activities are concentrated is higher compared to the case of the dispersion of such activities. For example, most of the time, agglomeration of activities corresponds to an agglomeration of population; it follows that the probability of having more casualties if any accident happens in such a place is higher. Moreover, a concentration of chemical (or other dangerous) firms and their output increases the risk of the propagation of any accident from one firm to another in the event of fire or explosion.

As a matter of fact, it is quite easy to verify that such a concentration exists in the chemical industry.[4] Agglomeration of activities in that sector is usually the result of positive externalities of proximity described by the economic geography models: in a monopolistically competitive manufacturing sector, increasing returns and market size effects lead firms to agglomerate. How effective are traditional environmental policies in reducing the risk of major catastrophic accidents, by reducing the concentration of dangerous activities? This is the question we address in this paper. If environmental taxes have strong implications for the profitability of polluting industries, environmental policies may have consequences, in the long run, on entry/exit decisions of firms. Moreover, policy instruments, most of the time, increase marginal costs (when the tax is an effluent fee tied directly to the polluting production) or/and fixed costs (when new high performance equipment is required) and consequently modify the degree of scale economies. As a consequence, the market structure, and then the incentive for firms to agglomerate, could be modified by traditional environmental policies. Behind this intuition is the idea that environmental policies could be a substitute to centrifugal forces and put the brakes on the tendency to agglomerate. This could explain why the Seveso Directive does not include specific recommendations in order to limit the concentration of risky activities.

If this intuition is not true, specific policies must combat the concentration of major risky activities.

Many papers have discussed the spatial dimension of environmental policies. Most of them consider an oligopoly market producing a homogeneous good (one monopoly in each region or country) and analyze the problem of plant relocation decisions in response to environmental restrictions (Motta and Thisse 1994;

4. In the case of France, more than 50 % of the Seveso type of establishment are located in 5 regions out of 24.

Markusen et al 1993; Markusen et al 1995; Hoel 1997; Petrakis and Xepapadeas 2003).[5] Other papers study the trade-off between the negative effects of deterioration in environmental quality and positive agglomeration externalities[6] in residential areas, in a spatial equilibrium of cities.[7] However, there are still two related issues where there is a lack of theoretical research into the spatial dimension of environmental problems. One is the differentiated-goods models and the other is the effect of environmental policies on the agglomeration of risky activities. This paper discusses both these questions and is organized as follows. We present first the model: using the Krugman's core-periphery model (1991), we introduce into the agents' welfare function a disutility of pollution. We show that, like any congestion cost, the disutility of pollution modifies the location equilibrium and reduces partially, but does not cancel, the incentive for firms to agglomerate. Then, we turn our attention to introducing traditional environmental policies. We show that environmental policies increasing fixed costs have different effects on market structure, production and welfare but have no effect on the firms' incentives to agglomerate. Our most important result is that environmental policies that increase marginal costs play a centripetal role and worsen the activities' concentration. Because traditional environmental policies cannot be considered as a substitute to a 'land-use planning' policy, we propose a specific environmental policy that limits the concentration of risky activities and we show the need for a spatial differentiation of environmental regulation. Finally, we conclude and give some suggestions for further research.

The Model

A Reminder of Krugman's Results[8]

In two regions, i=1,2, there are two categories of consumers, mobile workers and immobile farmers. The regions may differ only in one respect: the number L_i of workers. The overall number of workers (and farmers) is μ $(1-\mu)$; it is assumed that $L_1 = f\mu$ and $L_2 = (1-f)\mu$, with $0 \leq f \leq 1$. In each region, there are $(1-\mu)/2$ farmers.

Farmers and workers have different activities and therefore incomes but have identical preferences described by:

$$U = C_m^{\mu} C_{\alpha}^{1-\mu} \quad (1)$$

5. Note that the term 'environmental dumping' characterizes a situation where the government undertakes strategic low environmental standards policies in order to attract firm location.
6. Papageorgiou and Pines (2000) discuss the impact of externalities on agglomeration in cities.
7. See for example, Verhoef et al (2003). For a general analysis of urban agglomeration and dispersion, see Tabuchi (1998).
8. Krugman (1991a, 1991b). We follow Krugman's model and notation closely.

where C_a is the consumption of the homogeneous agricultural good (used as the base) and C_m is consumption of an aggregate of n manufactured goods defined by

$$C_m = \left[\sum_{k=1}^{n} C_k^{\frac{\sigma-1}{\sigma}}\right]^{\frac{\sigma}{\sigma-1}} \quad (2)$$

with $\sigma > 1$, or the elasticity of substitution among the manufactured goods (and the perceived price elasticity of demand).

The amount of labour l_k required to produce a quantity x_k of good k ($k = 1 \ldots n$) is

$$l_k = \alpha + \beta x_k \quad (3)$$

where α is the fixed cost and β a constant marginal cost. Increasing returns to scale imply that each firm produces a single product and each region is specialized in a given set of varieties. The firms are Chamberlinian monopolistic competitors and, in equilibrium, set a price P_i that is uniform within each region:[9]

$$P_i = \frac{\sigma}{\sigma - 1}\beta W_i \quad (i = 1, 2) \quad (4)$$

with W_i the wage rate of workers in region i.

Free entry and exit conditions (therefore zero-profit condition in the long term) imply that

$$x^* = \frac{\alpha}{\beta}(\sigma - 1) \quad (5)$$

where x^* is the equilibrium quantity produced by each firm, given the pricing rule, whatever the region. Note that x^* is constant and common to every active firm in the economy. Therefore, the associated equilibrium labour input l^* is also common

9. Because workers' wage is the same within a region, price is also the same for all varieties produced in one region. Consequently, given L_i only two variables remain in the model, P_1 and P_2 (or W_1 and W_2).

to every firm (see (3)).

The full employment condition determines the number of firms (and therefore the number of differentiated products) in each region:

$$n_i = \frac{L_i}{\alpha\sigma} \qquad \forall i = 1, 2 \quad (6)$$

Krugman assumes that the agricultural good can be freely transported from one region to the other.[10] Transportation costs for manufactured goods take Samuelson's iceberg form: $0 \le r \le 1$ is the fraction of one unit of manufactured good that, shipped from one region, reaches the other.

Demand for each industrial good is obtained by maximizing consumers' utility (given by (1) and (2)), subject to their budget constraint.

Equating supply (given by the free entry condition (5)) and demand for each good in both regions, together with the full employment condition (6), determines the equilibrium prices and wages for a given allocation of workers between regions, L_i (see Appendix).

Assuming that workers can move, without any cost,[11] from the low to the high real wage region,[12] Krugman shows that, with increasing returns and low transportation cost (when r is high), the larger region has the higher real wage because of the larger size of the local market: the result is a tendency to concentration. Figure 1 makes the point for $f = 0.55$ (region 1 is the large region). It depicts how U_1-U_2 varies with r for various values of μ, when $\sigma = 3$, $\alpha = 1$, $\beta = 0.01$.

For a sufficiently large level of r, the market-size effect becomes favourable to region 1: $U_1 > U_2$. The level of r for which U_1 becomes higher than U_2 decreases when m increases because there is more trade in industrial goods and the market size effect has more impact. The main feature here is that, when concentration starts, at the break point where U_1 (the workers' real wage or utility in region 1) becomes higher than U_2 (the workers' real wage or utility in region 2), it goes on with lower transportation (or other transaction) costs. The other important point is that the direction of migration is stable when f (the share of workers in region 1) increases. Because the market size increases with f, U_1-U_2 increases more and more when concentration occurs in region 1 until $f = 1$.

High risk activities and particularly chemical ones, involving the storage of dangerous chemical substances, produce differentiated goods in a monopolistically competitive market, with increasing returns. The market size effect is often amplified by backward and forward linkages between firms: as a result, firms cluster naturally.

10. Calmette and Le Pottier (1995) introduce a transportation cost for agricultural good and show that under certain conditions, this makes the concentration of activities less attractive (see also Fujita et al 1999, chap.7).
11. Ottavanio (1999) considers that migration is costly and depends on the rate of migration.
12. In that particular model, real wage is identical to the agent's utility U_i.

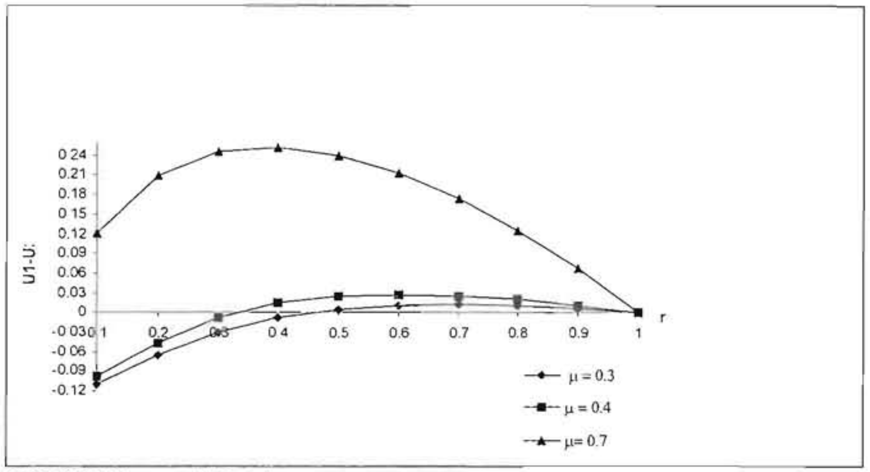

FIGURE 1 Krugman's Results

What is the impact on such a concentration if we assume now that the agents take into account the risk of pollution and accidents resulting from this agglomeration of risky activities? We turn now to analyze this question further.

The Disutility of Pollution

We consider now that firms are polluting and that pollution is a by-product of the manufactured goods production process. Assume that workers are harmed by pollution and take into account the disutility of that pollution when they decide to migrate or not. They move from the low to the high welfare region: in region 'i' the workers' welfare net of the disutility of pollution is defined by

$$S_i = U_i - D(E_i) \tag{7}$$

where U_i is the real wage in region i (given by (1)) and E_i is the total level of pollution in region i.[13] As assumed most of the time in the environmental literature, we consider that the relation between emission (e) and production by each firm is linear and given by $e = \theta x$, where $\theta > 0$ represents the firms' environmental performance.[14] Since $E_i = n_i e$, relation (7) may be rewritten as follows:

13. We assume that pollution is purely local: in each region the environment is only affected by the emissions in that region.
14. A lower θ means less polluting emissions.

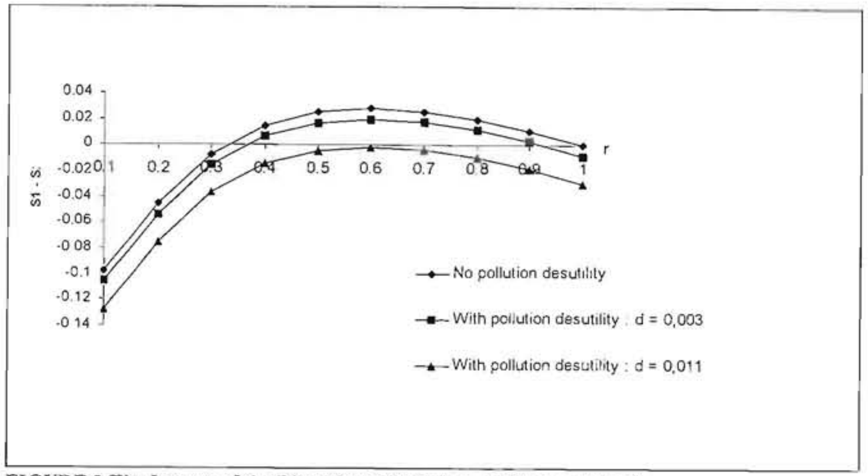

FIGURE 2 The Impact of the Disutility of Pollution on Workers' Welfare

$$S_i = U_i - D(n_i \theta x) \tag{7'}$$

where $D(n_i\ \theta x)$ measures the global negative impact of pollution on health or utility. The disutility resulting from the polluting effluent is increasing in the global emission, then in the number of firms (given by (6)) and the output per firm (given by (5)).[15] In the remainder of the article, it will be useful to work with the linear function $D(n_i\ \theta x) \equiv \delta n_i \theta x$ with $0 < \delta < 1$.

Clearly, the workers' welfare now has two components working in opposite directions: if region 1 is the larger region ($f > 0.5$), on one hand, it is more attractive to workers than the other region because the real wage is higher (the market size effect),[16] but, on the other hand, it is less attractive because the disutility of pollution increases (with n_i) in the region where the agglomeration occurs and plays the role of a centrifugal force. The result of the tension between centripetal and centrifugal forces depends on the relative values of the parameters μ, σ, θ and r and on the marginal damage δ. For given values of μ and σ, the effect of an increase in the marginal damage is to reduce the range of transportation costs for which a concentrated equilibrium is sustainable. Obviously, for given values of μ, σ, θ and r, there exists a limit value of δ such that workers are so frightened by the pollution that agglomeration of firms (and workers) never occurs. We illustrate this proposition in Figure 2, when region 1 is the larger region ($f = 0.55$).

We plot S_1-S_2, the difference between the two regions' workers welfare against the transportation cost r, for a high value ($\delta = 0.011$), medium ($\delta = 0.003$)

15. Remember that x is common to every active firm in both regions.
16. If the share of manufacturing in the economy (μ) and the economies of scale are sufficient, and if the transport cost is not prohibitive.

or zero value ($\delta = 0$) of the disutility of pollution. Remember that concentration occurs if (S_1-S_2) is positive, we see that when δ increases, the difference (S_1-S_2) goes down and the range of transportation costs for which concentration occurs is reduced and even cancelled for a high value of δ.

However it is easy to check that, most of the time in the real world, pollution, like any congestion cost, does not generate sufficient centrifugal forces to prevent the agglomeration of activities. The only effect of the disutility of pollution is to reduce the range of transportation costs for which the market size effect dominates the centrifugal force. If environmental directives aim at *the prevention of major-accident hazards involving dangerous substances* and, as accidents do continue to occur, at *the limitation of the consequences of such accidents not only for man (safety and health aspects) but also for the environment (environmental aspect)*,[17] then both aims should be followed by limiting the agglomeration of risky activities.

Are the common forms of environmental policies able to fulfill that task? This is the question we address now.

The Impact of Pollution Control on Agglomeration Equilibrium

It is well known that polluting agents need to be induced to internalize the social cost of pollution damage, otherwise they will engage in excessive levels of emission of pollutants. We assume that a national environmental regulator enforces necessary measures in **both** regions.

Firms, faced with a pollution control policy (a tax on the emissions or other pollution standards), must undertake a costly abatement effort in order to reduce their emission level, by reducing θ. This effort results in an increase in marginal cost $\beta(\theta)$ with $\beta'(\theta) < 0$. In the following section, we analyze the effects of a higher marginal cost.

Furthermore, as the Seveso Directive aims at the prevention of major-accident hazards involving dangerous chemicals, we assume that the environmental regulator enforces specific obligations on firms holding a large quantity of dangerous substances.[18] These obligations increase the fixed cost and we study their consequences in the following section. Let us emphasize that we take as a point of departure the goal of avoiding clustering of environmental risks, because of the scale effect discussed in the introduction. Moreover, we focus entirely on the costs imposed by the regulator: we are not concerned here with the choice among policy instruments,[19] nor by the optimal tax (or quota) level. We simply assume that the

17. Seveso II Directive, op.cit.
18. The two main obligations concern the introduction of Safety Management Systems (management factors have proven to be a significant causative factor in over 90 % of the accidents in the European Union since 1982) and the setting up of internal and external emergency plans.
19. For a survey, see Cropper and Oates (1992).

firms' behaviour is Pareto-efficient: given the announced policy instrument and the level of the tax on emissions (or quota), the polluting agent undertakes an effort that increases costs such that the marginal benefit from reduced pollution (reducing tax level) equals the marginal abatement cost.

The Impact of an Increasing Marginal Cost

Assume that firms have undertaken the optimal effort in order to minimize the tax they pay on emissions. As a consequence, in each region, the equilibrium labour input required to produce the equilibrium quantity x^* at the firm level is now

$$l^* = \alpha + \hat{\beta} x^* \tag{8}$$

where $\hat{\beta} > \beta$ is the new marginal cost resulting from the decrease in θ.

What is the impact of such environmental policy on the agents' welfare, then on their location decision? We have to consider the two components of S_i.

First, let us consider the centripetal force, the market size effect. It depends on the difference between real wages (U_1-U_2).

Several results are apparent from equations (4), (5) and (6).

Because firms are Chamberlinian monopolistic competitors, faced with a higher marginal cost, they lower their production level (5) and raise their price (4).[20] From (6) we see that the number of firms (and then the number of varieties) in each region is unchanged.

It follows that the global output $(n_i x^*)$ decreases in both regions and pollution, as a by-product of production, falls. This is the positive impact of the environmental policy.

The increase in marginal cost has the intuitive effect of lowering the agents' real income or utility. Farmers and workers' wages are unchanged (there is no need to modify nominal wages because supply and global demand fall in the same proportion when β increases[21]) but their real income is lowered, through higher prices. It is easy to check in equations (10) and (11) (in the Appendix) that workers' utilities (U_1 and U_2) decrease in the same proportion in both regions when β increases. Figure 3 depicts how the difference between *the workers' real wages* (U_1-U_2) varies with r, for various values of β, when $\sigma = 3$, $\alpha = 1$, $f = 0.55$. Because U_1 and U_2 fall in the same proportion with a higher value of β, the difference (U_1-U_2) falls also in the same proportion and obviously reaches zero ($U_1 = U_2$) for the same value of r whatever the value of β. The interesting result is that the break point, B, the point where the real wage becomes higher in the large region ($U_1 > U_2$), is the same whatever the marginal cost level. It follows that the centripetal

20. Note that Markusen (1997) obtains the same results in a model with homogeneous goods.
21. This is clear from equation (10) in the Appendix, if we remember that $P_i = (\sigma/\sigma\text{-}1)\,\beta W_i$.

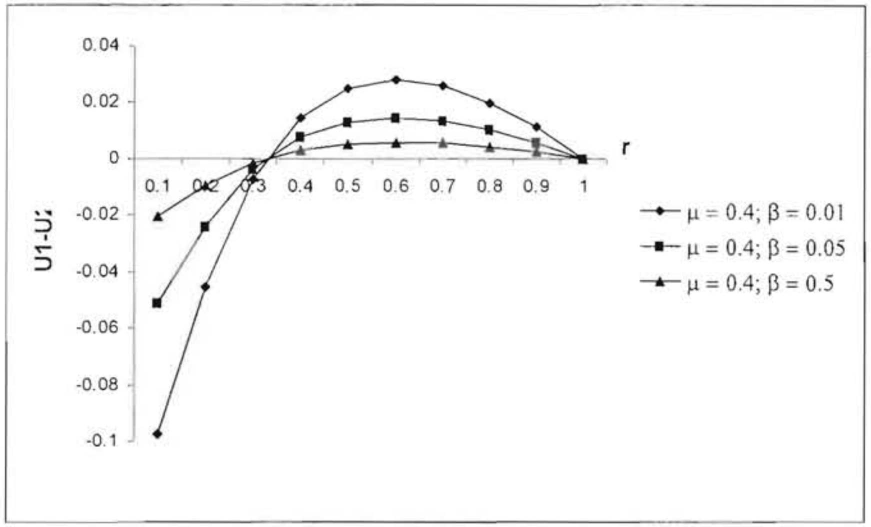

FIGURE 3 The Effect of an Increase in Marginal Cost on the Difference in Regions' Real Wages

force is unchanged by an environmental policy increasing marginal cost.

Let us consider now the centrifugal force. It depends on the difference between the regions' global disutility of pollution. We have underlined that pollution decreases in both regions with a higher marginal cost (because firms lower their production level and the number of firms n_i are unchanged). The important result here is that, because n_i is proportional to L_i (see (6)), the decrease in the global disutility of pollution ($\delta n_i \theta x$) is higher in the larger region. As a consequence, the difference between the regions' global disutility of pollution decreases and the centrifugal force is softened by the environmental policy. Because the centripetal force in unchanged, the most noticeable result of such an environmental policy is to worsen the tendency for firms to agglomerate. We illustrate this result in Figure 4 which depicts now how the difference between *the workers' welfare* (S_1-S_2) varies with r for various values of β, when $\sigma = 3$, $\alpha = 1$, $f = 0.55$, $\theta = 1$, $\delta = 0.03$ We see that the range of transportation costs for which concentration occurs (because $S_1 - S_2 > 0$) is larger with higher values of β.

As we have just seen, this section has addressed the question: is environmental policy able to stop the concentration of risky activities by increasing marginal cost? The answer is 'no'. To the contrary, such a policy stimulates agglomeration by reducing the effect of the centrifugal force and increasing the range of transportation costs for which the market size effect dominates.

We examine now the effect of an environmental policy increasing the fixed cost.

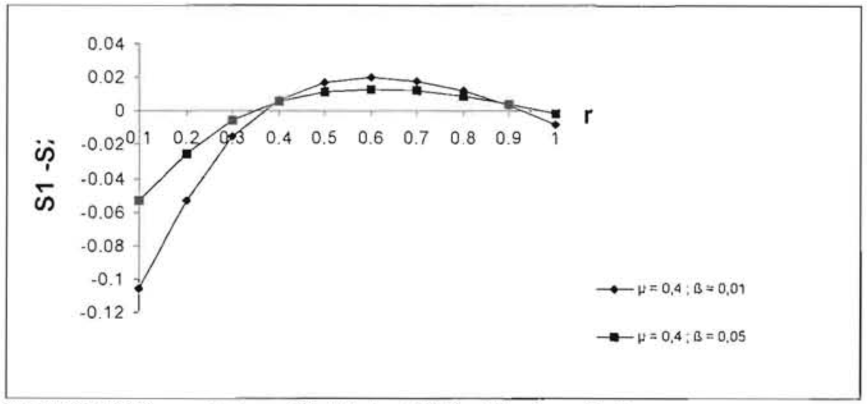

FIGURE 4 Difference between *The Workers' Welfare* Varying with R

The Impact of an Increasing Fixed Cost

Assume now that the environmental policy forces firms to increase plant fixed cost, without any effect on marginal cost.

The equilibrium labour input required to produce a quantity x^* of each good is now

$$l^* = \hat{\alpha} + \beta x^*$$

with $\hat{\alpha}$ ($\hat{\alpha} > \alpha$) the new fixed cost generated, by way of precaution, for the storage of dangerous substances and the setting up of emergency plans.

The implications of such a policy on entry-exit decisions of firms are intuitive and clear. The fixed cost increment is absorbed by exit of some firms: the number of firms (and then the number of varieties) falls (see (6)) and the remaining firms produce larger outputs (see (5)). However at the industry level, overall production, and thus the overall pollution level, are unchanged because the number of firms decreases in the same proportion the per firm output increases. Consequently, these market mechanisms insulate the degree of economies of scale in equilibrium from the fixed cost increment.

Prices and wages are unchanged. Nevertheless the agents' real wage (or utility) decreases because less varieties of goods are available.

The decrease in real wage, while manufactured prices and nominal wages are unchanged, may come as a surprise. This result arises from the particular form of the sub-utility function (2) which expresses the agents' preference for variety. Real wage equals $(W_i/I_p) = U_i$ where I_p is the price index of manufactured goods for a consumer. In region 1, it is equal to

$$I_p = \left[n_1 P_1^{1-\sigma} + n_2 \frac{P_2^{1-\sigma}}{r} \right]^{\frac{1}{1-\sigma}} \quad \bullet \qquad (9)$$

Remembering that $\sigma > 1$, it is easy to check that the price index increases (meaning that the real wage decreases) when the number of firms falls, even if prices are unchanged.

Relation (6) shows that firms exit in the same proportion in both regions when the fixed cost increases and whatever the value of α, the varieties produced in the regions are always proportional to L_i. We have:

$$\frac{n_1}{n_2} = \frac{f}{1-f}, \qquad \forall \alpha \quad \bullet$$

It is clear from equations (10) and (11) (in the Appendix) that the only change in the workers' utility is the number of consumed products, n_i. The result is that agents' utility falls in the same proportion in both regions with increasing fixed cost and once again, the difference $(U_1 - U_2)$ falls in the same proportion and reaches zero for the same value of r: the break point, B, is not modified and the centripetal force is unchanged.

From equations (5) and (6), it is clear that the centrifugal force is also unchanged because the product $(n_i x)$ is the same whatever the value of the fixed cost. Obviously, in this type of Dixit-Stiglitz[22] model of monopolistic competition, environmental policies increasing fixed cost have no impact on the incentives for firms to agglomerate and are not able to stop concentration of risky activities. The most negative point is that these policies enlarge the conditions leading to concentration when they involve a higher marginal cost.

We propose now an approach to organize the control of major risks and 'land-use planning' in hazardous chemical establishments.

A Spatial Differentiation of Environmental Policies

Clearly, the above results show that it is necessary to break the symmetry of the regions in order to stop the concentration of high risk manufactured activities in a single one.

We must design spatial differentiation into environmental policies. The solution is to allow the regulator to fix different taxes (or other instruments) on firms according to their location.

The larger the number of firms, the stronger the effect of emissions on local

22. Dixit and Stiglitz (1977).

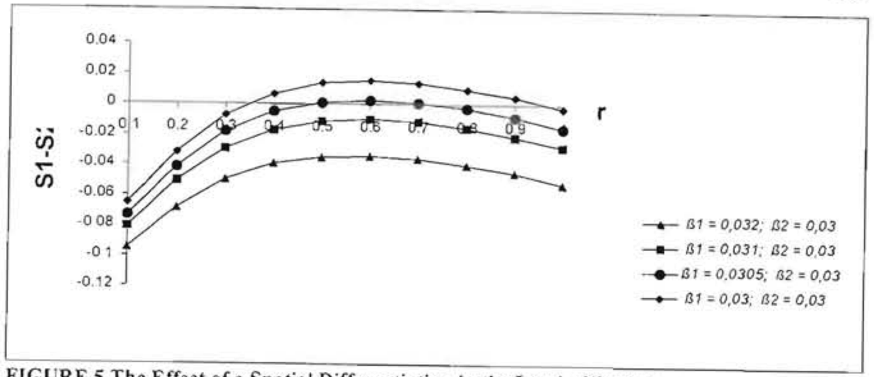

FIGURE 5 The Effect of a Spatial Differentiation in the Level of Emissions

environmental quality: why would the regulator not levy emission fees according to the concentration level? In that case, the emission fee in each region could be weighted by the number of firms. More simply, we assume here that the regulator requires a higher environmental performance (a lower level of emission θ) for firms located in the larger region. As a consequence, with $f > 0.5, \hat{\beta}_1(\theta_1) > \hat{\beta}_2(\theta_2)$.

In response to the marginal cost increase, the quantity produced by each firm in both regions falls (5) and firms set higher prices (4). But, now the spatial differentiation of environmental regulation gives a comparative advantage to the smaller region and reduces the range of transportation costs for which concentration occurs. It follows that there exists a difference between marginal costs $(\hat{\beta}_1 - \hat{\beta}_2)$ such that the smaller region becomes attractive.

With $\hat{x}_2^* > \hat{x}_1^*$ and $\hat{P}_1 > \hat{P}_2$, the ratio of the equilibrium nominal wages $\hat{W}_1 / \hat{W}_2$ falls through the equality between supply and global demand;[23] nominal and real wages are higher in the smaller region and the centripetal force (the market size effect) is now broken. We illustrate this result in Figure 5.[24]

We can see that the difference $(S_1 - S_2)$ decreases when $\hat{\beta}_1$ increases relatively to $\hat{\beta}_2$ and the entire curve becomes negative, whatever the values of r, for a sufficient difference between the marginal costs (then between the required levels of emissions). In that case, starting with $f = 0.55$, workers will migrate from region 1 to region 2, until $f = 0.5$. At this point, there is no more need to differentiate environmental policy. The threat to be more heavily penalized in a large region will prevent firms from agglomerating.

At this point, differentiation in environmental regulation, by giving a comparative disadvantage to the larger region, generates sufficient centrifugal forces to counterbalance the market size effect and avoid concentration of high risk activities.

23. It is easy to check this proposition by replacing, in (9) (in the Appendix), β by $\hat{\beta}_1$ in the first equation and by $\hat{\beta}_2$ in the second equation (with $\hat{\beta}_1 > \hat{\beta}_2$). In the preceding case, with the same increase in marginal cost in both countries, the symmetry in the firms' reaction in term of production level ($x_2 = x_1$) and prices (P_1/P_2 unmodified) left unchanged the nominal wages.

24. With $\alpha = 1$, $\hat{\beta}_2 = 0.03$, $\mu = 0.4$, $\theta = 1$, $\delta = 0.03$.

Conclusion

This paper has dealt with the problem of concentration of high risk activities, for example in the chemical industry. We explored the question whether traditional environmental policies were able to combat firms' tendency to cluster. The growing literature on the importance of economies of scale as a determinant of agglomeration seems to suggest that environmental regulation impacting on marginal or/and fixed costs – and therefore on the degree of scale economies – should have an effect on firms' incentives to agglomerate.

Using a two-region equilibrium model in a monopolistic competition framework, 'à la Krugman', we first demonstrated that the increase in marginal cost, induced by regulation, amplifies the concentration of risky activities and the risk of a major industrial catastrophe. Second, we show that environmental regulation leading to an increase in fixed cost has different impacts on agents' welfare and firms, for the short and long run, but leaves unchanged the tendency for firms and workers to agglomerate. The main reason is that, in this particular model, all scale effects work through the number of product varieties and regions are perfectly symmetric, excepted in one respect: the number of workers.

An important result of our analysis is that if environmental regulators do want to stop agglomeration of high risky activities, they must develop specific policies in order to achieve this objective. One approach is to fix different environmental standards on firms according to their location. We show that the regulator is thereby able to stop agglomeration by requiring a higher effort (a lower level of emission) for firms located in the larger region. This policy gives a comparative disadvantage to the larger region which cannot absorb a higher marginal cost, except by increasing prices and lowering production level.

A final important issue that we have not considered in our model is the direct backward and forward linkages existing in the chemical industry which surely worsen the firms' incentives to cluster. In such an industry, firms produce output for agents' consumption and intermediate goods: manufacturing uses manufacturing as an input. Further research could therefore extend our analysis and verify our results.

Appendix

Relation (1) yields the familiar result that agents spend a share μ of their income on manufactured goods and a share $(1-\mu)$ on agriculture.

Because manufactured goods are subject to an 'iceberg' transport cost, the delivered price in region 1 for a good produced in region 2 is P_2 / r when the mill price is P_2.

Given workers and farmers' income[25] and a set of prices, P_i for goods produced in region i and P_j / r for goods imported from region j, it is a straightforward exercise to maximize agents' utility (2) subject to their budget constraint.

25. Remember that there are $(1-\mu)/2$ farmers in each region, each of them producing one unit of the homogeneous agricultural good at the price $P_a=1$; therefore the global farmers' income in each region is $(1-\mu)/2$.

Equating supply and global demand for each industrial good in both countries yields a pair of equations (using (5))

$$\begin{aligned}
\frac{\alpha}{\beta}(\sigma-1) &= \frac{\mu}{P_1}\left[\frac{W_1L_1+\frac{1-\mu}{2}}{n_1+n_2\left(\frac{W_1r}{W_2}\right)^{\sigma-1}}+\frac{W_2L_2+\frac{1-\mu}{2}}{n_1+n_2\left(\frac{W_1}{W_2r}\right)^{\sigma-1}}\right] \\
\frac{\alpha}{\beta}(\sigma-1) &= \frac{\mu}{P_2}\left[\frac{W_1L_1+\frac{1-\mu}{2}}{n_2+n_1\left(\frac{W_2}{W_1r}\right)^{\sigma-1}}+\frac{W_2L_2+\frac{1-\mu}{2}}{n_2+n_1\left(\frac{W_2r}{W_1}\right)^{\sigma-1}}\right]
\end{aligned} \tag{10}$$

which determines the equilibrium prices and wages (using (4) and (6)), for a given distribution of workers (L_1 and L_2).

Using the results of maximizing agents' utility and relation (1), we can now write workers' utility in each region:

$$U_1 = ((1-\mu)W_1)^{(1-\mu)} \left[n_1\left[\frac{1}{P_1}\frac{\mu W_1}{n_1+n_2\left(\frac{W_2}{W_1r}\right)^{1-\sigma}}\right]^{\left(\frac{\sigma-1}{\sigma}\right)} + n_2\left[\frac{1}{P_2}\frac{\mu W_1 r}{n_2+n_1\left(\frac{W_1}{W_2}r\right)^{1-\sigma}}\right]^{\left(\frac{\sigma-1}{\sigma}\right)}\right]^{\left(\frac{\mu\sigma}{\sigma-1}\right)} \tag{11}$$

$$U_2 = ((1-\mu)W_2)^{(1-\mu)} \left[n_1 \left[\frac{1}{P_1} \frac{\mu W_2 r}{n_1 + n_2 \left(\frac{W_2}{W_1} r \right)^{1-\sigma}} \right]^{\left(\frac{\sigma-1}{\sigma}\right)} + n_2 \left[\frac{1}{P_2} \frac{\mu W_2}{n_2 + n_1 \left(\frac{W_1}{W_2 r} \right)^{1-\sigma}} \right]^{\left(\frac{\sigma-1}{\sigma}\right)} \right]^{\left(\frac{\mu\sigma}{\sigma-1}\right)} \quad (12)$$

Workers will move from region 2 to region 1 (and, according to Krugman's conclusions, f and L_1 will increase until f=1 and L_1=μ) if $U_1 > U_2$.

The crucial question is how U_1/U_2 varies with f. For example, starting with a situation where $f = 0.5$, we know that real wages are the same in both regions and $U_1 = U_2$. If it happens, by history[26] or accident, that f increases (namely region 1 becomes the larger one), two cases are possible: if, with $f > 0.5$, $U_1 < U_2$, then some workers will migrate to region 2 until $f = 0.5$. In that first case, U_1/U_2 decreases with f: the result is a regional convergence. On the contrary, if $U_1 > U_2$, region 2 workers will tend to migrate to the large region and, in that case, because U_1/U_2 increases with f, the result is a regional divergence.

In this paper, we assume that region 1 is the larger one (f=0.55). In our simulations, we consider the variation of the difference $(U_1 - U_2)$ when transportation cost decreases, namely when r tends to 1, with $\sigma = 3$.

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