Project to Assess the Impact of the New EU Chemicals Strategy (REACH) and to Develop a Model -Economic Model and MatLab Code

Final Report

Prepared for
the Department for Environment,
Food and Rural Affairs
and
the Department of Trade
and Industry

RPA

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1 Economic modelling of supply chains

1.1 Objectives of the economic model

The analysis aims at assessing the economic costs along the supply chain of the testing and registration phase of the new chemicals policy.[1] This analysis will include:

- impact on the prices of the chemical and of the products that successively use the chemical along the supply chain
- how these changes in prices affect downstream producers and final users
- impact on availability of product varieties (product withdrawals)
- how these withdrawals affect downstream producers and final users.

1.2 Literature sources

We draw on different sources from the economic literature to describe the competitive interaction along the chemicals' supply chain.

The BE-COMP framework that we describe in more detail below is well explained in chapter 6 of Richard Baldwin and Charles Wyplosz book[2].

We also draw on the modelling techniques developed for DG enterprise by Canton and Allen (2003)[3]. This model is particularly suited to address the reaction of chemical producers to the change in fixed costs that the REACH proposals entail but falls short of an analysis of oligopolistic interaction.

We thus use a model of bilateral oligopoly to describe how a cost shock upstream will affect decisions and outcomes both upstream and downstream. For this we follow Corbett and Karmarkar (2001)[4].

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[1] It therefore does not cover the potential effects of the subsequent evaluation and authorisation phases, nor the associated potential benefits for human health and the environment.

[2] Richard Baldwin and Charles Wyplosz, The Economics of European Integration, McGraw Hill, December 2003.

[3] Canton and Allen (2003): "A microeconomic model to assess the economic impacts of the EU's new chemicals policy"

[4] Corbett, C. J., and Karmarkar, U. S. (2001), "Competition and Structure in Serial Supply Chains with Deterministic Demand," Management Science 47, 966-978.

2 The BE-COMP framework

The BE curve

We assume economies of scale in the production of chemical substances, represented by the presence of fixed costs. This signifies that unit costs decrease with quantity produced. Production costs have a fixed cost (FC) component and a marginal cost (MC) component. This assumption implies that in an equilibrium with larger number of firms, as each firm produces less output, average costs are higher and firms require a higher mark-up above MC in order to break-even. Conversely, when the equilibrium number of firms decreases, each firm produces larger output, has lower unit costs and requires a lower mark-up in order to break-even. This relationship is represented by the break-even curve (BE) in the diagram below. The BE curve is a reflection of the cost structure of the chemical industry.

For an individual firm the break-even condition is given by:

$$pq = FC + MCq$$

With n symmetrical firms we have that $q = \frac{Q}{n}$, so that for each firm

$$\left(p - MC\right)\frac{Q}{n} = FC$$

or

$$markup = \frac{nFC}{Q}$$ [5]

The interpretation of the expression above is that, as the number of firms increases, the mark-up has to go up. In addition, we can also see that if FC (fixed costs) increases, break-even can be restored by a combination of higher mark-ups and lower number of firms.

The COMP curve

Competition among producers of the chemical substance will be tougher as their number increases. This is consistent with the Cournot-Nash model as well as other commonly used models of competition in oligopoly markets. When we increase the number of firms, competition among them is more aggressive and the mark-up consequently decreases. This relationship is represented by the "competition curve" (COMP) in the diagram below. In the limit, with a very large number of firms, mark-up tends to zero, the asymptote of the COMP curve. The COMP curve is a reflection of the demand conditions for the chemical substance.

In the model that we propose, producers compete as an oligopoly among them, but also have to consider the actions of a second group of oligopolists, the processors. This means that the COMP curve can be represented in the graph below as long as

[5] Note also that this expression explains the straight-line shape that we see in the BE-COMP graphic depiction below: break-even mark-up levels increase linearly with change sin the number of firms.

we hold fixed the number of oligopolists in the downstream market. It may however be the case that a change in the equilibrium number of producers will lead to a change in the equilibrium (or sustainable, or stable) number of processors.

There are however a number of particular cases where particular functional forms of the final demand curve imply that the equilibrium mark-ups in the upper tier of the market are independent of the number of firms downstream. Tyagi (1999)[6] identifies a number of these cases.

With this proviso, and for the particular case of a linear demand function of the form $p = a - bQ$, we can write the expression for the COMP curve as:

$$p = \frac{1}{n+1}\left(a - MC_d\right) + \frac{n}{n+1} MC$$

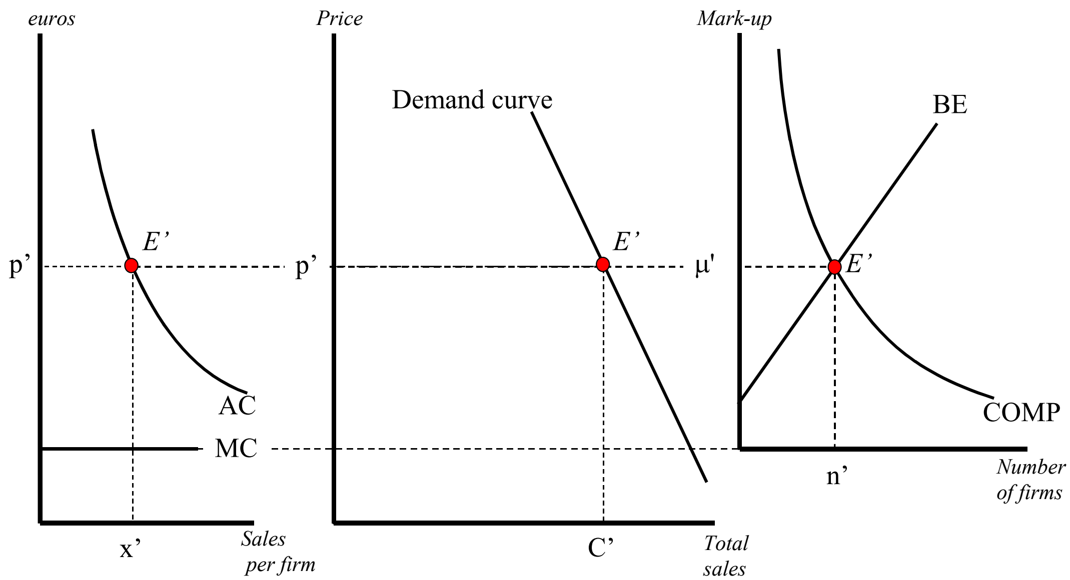
where MC_d is the marginal cost of the downstream tier. The explanation for this expression can be found in our section on the bilateral oligopoly model, where the full set of equations is deduced from first principles. In the setting of Section 3.2, Sub-section 3.2.1, the COMP equation above corresponds to equation (2) there.

In accordance with our intuition, the expression above tells us that as the number of competitors increases the mark-up decreases. It also shows that the impact of an extra competitor on mark-ups is stronger when there are very few and becomes smaller and smaller as the number of competitors increases.

Equilibrium in the BE-COMP framework

The intersection of the BE and the COMP curves gives us the equilibrium number of firms and the equilibrium level of mark-up. The mark-up added to MC gives us the corresponding price and using the aggregate demand we can figure out the total quantity sold in the market. Given this price and the break-even (or zero profit) condition, we can compute the level of sales per firm.

[6] Tyagi, R. K., 1999, 'On the effects of downstream entry', Management Science, 45: 59 – 73.



From Baldwin and Wyplosz (2003) op. cit.

Impact of a fixed costs shift

When a shift in fixed costs occurs (as in the case of that resulting from the implementation of the REACH program) the profits of chemical producers decrease and it is likely that some production of some substances will no longer break-even. Relative to the situation prior to the cost shift, firms now require a larger mark-up in order to break-even. This corresponds to an upward shift of the BE curve. A higher equilibrium mark-up in this market translates into higher input prices for downstream processors.

Processors, in turn, face a demand for their output as well as competition from other processors of identical or similar products. The ability for processors to absorb input price increases will depend on the level of competition that they face and the elasticity of demand for their products.

So far we have interpreted the diagram as a representation of a supply chain for a single product. It is however possible to think of this as a representation of a market where several varieties are being offered to buyers and where, as a result of a fixed cost increase, some of these varieties may be withdrawn from the market. In that sense, this diagram can also be seen as providing an intuitive representation of the mechanics of the model by Canton and Allen for DG Enterprise, although their model does not allow for more than one level of oligopolistic interaction.

3 A simple model of bilateral oligopoly

We present a model with three tiers – in the first two tiers we allow for the interaction of a small number of firms as a bilateral oligopoly. In the final tier we have consumers who are represented by a demand function.

Fixed costs affect the decision to operate or not on a given market and/or the decision to initiate or cease the production of certain products.

We start with a characterisation of the initial equilibrium. This includes: the number of firms producing at each tier; the quantity produced by each and in total; and the price in each tier. This information allows us to know the profit of each firm and thus the maximum level of fixed cost that can be sustained under the current market structure.

When a program such as REACH is implemented, it brings about an increase in fixed costs – this increase is not permanent but we may consider the present value of a flow of payments that would cover this increase in costs.

For example, if we have to spend an extra £1,000 on a given product for registration and certification this can be amortised over a period of say 5 years with a certain interest rate so that the increase in fixed costs may be only slightly more than £200. We take this increase and compare it with the current gap between operating profits and fixed costs. In some cases we will find that the operation is no longer viable under the new level of fixed costs. In this case we will consider the possibility of 1 firm leaving the market. We then re-compute the bilateral oligopoly equilibrium and consider the new level of profits and check whether or not this is now higher than the increase in fixed costs. We continue in this manner until enough firms leave so that the new level of profits is high enough to cover the new level of fixed costs. This will give us a new equilibrium with a different number of firms and different prices on each market.

It is possible that we will also see a change in the number of firms in the downstream tier. The fixed costs downstream have not changed but as the number of firms in the upstream tier decreases it is possible that the downstream firms lose relative bargaining power as a group and their profits may be affected as well. This may necessitate that some firms leave the downstream market for a new equilibrium to be reached.

3.1 Elements of the model

At producer level

1. We will compute equilibrium mark-up levels in a market with n_2 producers and n_1 processors, and bilateral oligopoly interaction among them.
2. We will let n_2 (the number of producers) vary while holding fixed n_1 (the number of processors). This will allow us to construct an equation describing how the mark-up changes with the number of producers

3. We will compute the break-even level of mark-up for producers, as a function of n_2 holding n_1 fixed.

4. When the REACH program enters into effect, there is an upward shift in the level of fixed costs for chemical substance producers. This will affect the break-even conditions described in 3 but will not, in a first approach, affect the competitive interaction between producers and processors

5. As a result of the change in fixed costs, the equilibrium number of producers is likely to decrease, and in any event the equilibrium level of mark-up will go up. The increased mark-up will correspond to an increase in variable costs for processors.

6. We have to verify whether the number of processors (that we are holding fixed so far) also needs to change so that a new stable outcome is reached. When the number of producers changes, the number of processors may no longer be an equilibrium. If processors start making losses then we should see the number of processors decrease, while if their profits increase we may expect to see entry into that market.

At processor level

1. Processors face a demand for their product which is mainly characterised by an elasticity of demand

2. As a result of REACH, and as a result of the increase in mark-ups by chemical producers, processors see an increase in the price of one of their inputs. This will have an impact on the price at which they sell their output. This impact depends on: the weight of that input in total production costs; the competitive conditions describing interaction with other processors of close substitute products; and the elasticity of demand.

At final consumer level

1. Consumers are described by an aggregate demand function.

3.2 Details of the model

The impact of a change in costs upstream will reverberate throughout the supply chain in a way that depends on a number of factors, namely:

1 – the initial number of firms in each of the tiers of the supply chain

2 – how significant the change in costs is relative to current levels of fixed costs and of variable costs

3 – the characteristics of final demand, namely its price elasticity

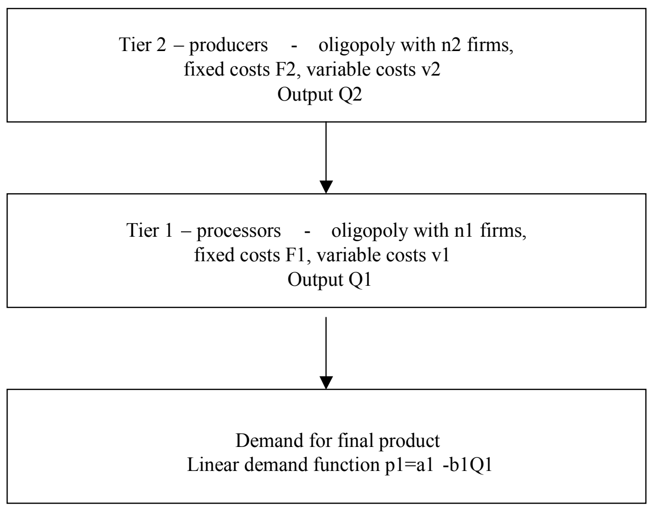
In the model we will consider a shock where fixed costs go up while variable costs do not. We assume that there are a certain number of producers on each level of the supply chain. We start with a certain equilibrium which will be disturbed by the change in fixed costs.

We can work with just one substance at a time. Consider a substance which is produced by an oligopoly of firms and bought by another oligopoly of firms. There is at present a certain cost of entry and a certain equilibrium number of firms in each tier. Next we consider an increase in the cost of entry and re-compute the equilibrium.

We do this following the model by Corbett and Karmarkar, which we describe in more detail below.

3.2.1 Equations

We assume two tiers in the supply chain – Tier 1 uses as inputs the outputs from Tier 2.



In the linear inverse demand function, a_1 and b_1 are parameters, Q_1 is the quantity supplied to the market and p_1 is the price.

Suppose there are n_1 firms in the downstream tier.

We assume Cournot-type competition. Each downstream firm chooses a production level $q_{1,j}$, taking the quantity produced by other firms as given.

Each downstream firm uses an input from the upstream tier. We assume that one unit of this input is required in the production of one unit of tier 1 output. This input (the output from tier 2 production) has price p_2.

Gross profit for a downstream firm is given by:

$$\Pi_{1,j} = \left(p_1 - v_{1,j} - p_2\right)q_{1,j} = \left(a_1 - b_1 Q_1 - v_{1,j} - p_2\right)q_{1,j}$$

where $v_{1,j}$ is that firm's variable unit production cost.

First order conditions are sufficient for a maximum and are given by:

$$q_{1,j} = \frac{\left(a_1 - v_{1j} - p_2\right)}{b_1} - Q_1$$

If tier 1 has n_1 firms all with the same variable cost $v_{1,j} = v_1$, then the system of equations defining q1,j has a symmetric solution $q_{1,j} = q_1 = \frac{Q_1}{n_1}$

This solves into:

$$q_1 = (a_1 - v_1 - p_2)/((n_1 + 1)b_1),$$

or

$$Q_1 = \frac{n_1}{n_1 + 1}\frac{a_1 - v_1 - p_2}{b_1},$$

The prices in the two tiers are inter-dependent with the relationship given by:

$$p_1 = \frac{1}{n_1 + 1}a_1 + \frac{n_1}{n_1 + 1}(v_1 + p_2)$$

We know that in this market the demand for the input produced in tier 2 is derived from the demand for output in tier 1. Given our assumption that one unit of the input is required for every unit of output, we have that $Q_1 = Q_2$, and so:

$$Q_2 = \frac{n_1}{n_1 + 1}\frac{a_1 - v_1 - p_2}{b_1} \quad \Rightarrow \quad p_2 = (a_1 - v_1) - b_1\left(\frac{n_1 + 1}{n_1}\right)Q_2$$

We now maximise profits in tier 2:

$$\Pi_{2j} = (p_2 - v_2)q_{2j} = \left(a_1 - v_1 - b_1 Q_2\left(\frac{1 + n_1}{n_1}\right) - v_2\right)q_{2j}$$

from first order conditions we obtain:

$$q_{2j} = \left(\frac{n_1}{n_1 + 1}\right)\frac{a_1 - v_1 - v_2}{b_1} - Q_2$$

Which we can aggregate over all firms in tier 2 to obtain the solution for the symmetric equilibrium:

$$(1)\ Q_1 = Q_2 = \left(\frac{n_1 n_2}{(n_1 + 1)(n_2 + 1)}\right)\frac{a_2 - v_1 - v_2}{b_1}$$

We are then in a position to compute the equilibrium prices in the two tiers:

$$(2)\ p_2 = \left(\frac{1}{n_2 + 1}\right)(a_1 - v_1) + \left(\frac{n_2}{n_2 + 1}\right)v_2$$

$$(3)\ p_1 = a_1 - \frac{n_1 n_2 (a_1 - v_1 - v_2)}{(n_1 + 1)(n_2 + 1)}$$

Substituting back and after some manipulation, we finally obtain[7]:

$$(4)\ \Pi_1(n_1,n_2)=\frac{1}{b_1}\left(\frac{n_2}{n_2+1}\right)^2\left(\frac{a_1-v_1-v_2}{n_1+1}\right)^2$$

$$(5)\ \Pi_2(n_1,n_2)=\frac{1}{b_1}\left(\frac{n_1}{n_1+1}\right)\left(\frac{a_1-v_1-v_2}{n_2+1}\right)^2$$

Given these results it is then possible to analyse viability and stability of supply chain structures. In a viable structure all firms make non-negative net profits (which include the fixed costs to be incurred for registering substances). A structure is stable if no firm has an incentive to reverse its decision whether or not to be in that market.

When a fixed cost increase occurs we may find that the current structure is no longer an equilibrium. We would then re-compute equilibrium profits with one less firm in the upstream tier and check whether that would correspond to a new equilibrium. We would proceed in iterations until a new stable arrangement were found.

The computations depicted here can be extended to a supply chain with any number of tiers.

3.3 Equilibrium number of firms

The conditions for (n_1,n_2) to be an equilibrium market structure are:

$$\Pi_1(n_1+1,n_2)\le F_1\le\Pi_1(n_1,n_2)$$

and

$$\Pi_2(n_1,n_2+1)\le F_2\le\Pi_2(n_1,n_2)$$

Therefore, as a consequence of an increase in fixed costs it may occur that the current number of firms is no longer an equilibrium. It is possible that the equilibrium will be restored if one firm leaves the upstream market. This will be the case if:

$$\Pi_2(n_1,n_2)\le F_2+\varepsilon\le\Pi_2(n_1,n_2-1)$$

We will then need to check whether we still have

$$\Pi_1(n_1,n_2-1)\ge F_1$$

because if that is not the case, then the number of firms in the downstream market must also change.

3.4 Impact of fixed cost shock on prices

When a fixed cost shock occurs, we have first to find a new pair (n'_1,n'_2) that constitutes a new equilibrium for our supply chain. Once we have that we can readily compute the change in prices for both producers and processors, and these will be given by:

[7] These equations are for the profits excluding fixed costs.

$$\Delta p_2 = \left[\left(\frac{1}{n'_2+1}\right)-\left(\frac{1}{n_2+1}\right)\right]a_2 + \left[\left(\frac{n'_2}{n'_2+1}\right)-\left(\frac{n_2}{n_2+1}\right)\right]v_2$$

$$\Delta p_1 = \frac{n_1 n_2 (a_1 - v_1 - v_2)}{(n_1+1)(n_2+1)} - \frac{n'_1 n'_2 (a_1 - v_1 - v_2)}{(n'_1+1)(n'_2+1)}$$

We may expect $n'_2 < n_2$ and it is possible that n_1 remains unchanged if the change in fixed costs is relatively small.

3.5 Extension for the case of many substances

For a number of industries it will be relevant the fact that the shock in fixed costs may cause producers of particular substances to cease production. In this case we can expect that the processors will have to either produce a given compound with a smaller number of substances or find substitutes for the substances that were lost.

One very simple way to incorporate the possible effects of this into our model is to consider that, once one or more substances are lost to a given supply chain, the resulting output will be less valuable for final users. This is similar to assuming that it costs more to processors to create an output that final users value in the same way as what they were using before the disappearance of substances. We can consider at least two different ways in which this effect can be modelled. 1) Upstream producers can be seen as each producing a different substance (or set of substances) and these substances all need to be taken together in order to produce the final user good; and 2) upstream producers are perfectly symmetric in terms of the substances that they ultimately choose to produce but as costs increase they may reduce the number of varieties offered thus impacting on the downstream producers' costs and/or on final users' valuations.

3.5.1 Different substances by different producers

Beginning with the first alternative, we can incorporate the impact of reduced availability of substances through a change in the final demand function to reflect the notion that greater availability of substances increases final users' valuation. We can consider the case where each upstream producer produces a set of substances and there is no overlap over substances produced by different producers. One way to model this is to re-write the demand function as:

$$p_1 = a_1 n_2 - b_1 Q_1$$

In this way, when the number of upstream producers decreases, the value of the final good for users also decreases. We can parameterise this effect in many different ways and choose, depending on the industry, the functional form that is the most appropriate. For example, if we wanted the effect of the availability of the different substances to be less pronounced we could replace the equation above by:

$$p_1 = a_1 \sqrt{n_2} - b_1 Q_1$$

More generally, we can represent these two examples as particular cases of a class of demand functions given by:

$$p_1 = a_1\left(\frac{n_2}{\alpha}\right)^{\gamma} - b_1 Q_1$$

Here, alpha is used for scaling and gamma controls the impact on demand valuation of additional increases in the number of substances. Gamma is a number between 0 and 1, so that additional increases in substance variety have decreasing positive impact on corresponding demand valuations.

In addition, we could generalise further by allowing some substances to "count more" than others, by assuming an effect also on the slope of the demand curve, etc.

3.5.2 Symmetric production of different substances

The modelling approach above applies better to supply chains where each substance is a specialised output of a particular firm. An alternative is to consider a situation where all substances are produced by all firms. This may also correspond to a situation where the number of substances used downstream is in the hundreds or even in the thousands. In such cases it is likely that the upstream production has considerable overlap among different producers. A stylised way to present this is to assume symmetric producers, each one producing the same (very large) set of substances.

One way to do this is to re-write the demand function as:

$$p = a\left(\frac{NS}{\alpha}\right)^{\gamma} - bQ\,,$$

where NS represents number of substances and, as above, alpha is used for scaling while gamma controls the impact on demand valuation of additional increases in the number of substances. Again, gamma is a number between 0 and 1 so that additional increases in substance variety have decreasing positive impact on corresponding demand valuations.

In this formulation, upstream producers decide on the number of substances that is optimal for them to produce. This decision takes into account the fixed cost per substance (which increases as a result of REACH) and the higher price that they receive for their output when the number of substances offered is higher.

We illustrate the impact of this formulation on our model in the simulation chapter where we apply the bilateral oligopoly model to the can coatings industry.

3.6 Extension to allow for banning of substances

A potentially important impact of REACH for some industries may be felt if one or more substances fail to meet the new, stricter safety requirements and are, consequently, banned.

The impact of this may be felt in a number of ways, depending on the characteristics of the product and the organisation of the supply chain. A first modelling decision is to choose whether we want the number of substances to be connected to the number of firms or not. In other words, choose whether the upstream firms' substances overlap with each other or not. If they do, we should use a variant of the model presented in 3.5.1, if they do not, we should choose a variant of that in 3.5.2.

We expand on these two alternatives below.

3.6.1 Banned substance affects only one producer

In this case, we may find, as a result of the banning, that the number of producers is reduced. This has both a positive and a negative impact on upstream producers. It benefits the remaining producers as each one has a relative gain in terms of market power. On the other hand, it hurts them as the valuation from downstream users and/or final demand decreases.

The net effect for the upstream producers is thus ambiguous. As for the downstream producers and for the final users, it is unambiguously negative as they lose both because the characteristics of the upstream output are less valued and because prices increase due to stronger exercise of market power in the upper tier of the market.

An example illustrating the impact of this type of assumptions is provided in the following chapter under the heading Example 6.

3.6.2 Banned substance affects all producers symmetrically

This situation could be modelled in a similar way to the analysis that we include in our section on model simulation applied to the can coatings sector. The only change we would have to make on the model is, instead of letting firms choose the optimal number of substances to produce, impose a reduction of one or more on the number of substances that they are allowed to produce. This would have similar impacts to the ones described in the simulation section (Section 5) except that there would not be a simultaneous change in the fixed costs.

3.7 The analysis of barriers to entry and exit

Barriers to entry and exit are often an important component of the market structure for a given industry or supply chain. Barriers to entry may facilitate the exercise of market power by incumbents, which in turn may imply that some or all incumbents have supra-normal profit levels. This situation can be sustained without attracting entry by new competitors precisely because of the presence of barriers to entry. Barriers to exit imply that inefficient production arrangements may remain in place long after they have become economically unviable.

The formulation of our model here has been thought for the purpose of carrying out simulation exercises. The model thus starts out with a given number of firms in each industry tier. We assume that this number will be known at the time the model simulation is performed. If, in the industry under study, barriers to entry are prevalent, then the initial number of firms observed will be lower than the "equilibrium" number of firms for a similar industry without the barriers to entry. This will be reflected in the initial conditions of the industry by, potentially, a higher profit margin than would otherwise be expected. The shocks that we consider for the purpose of the analysis of the impact of REACH are not shocks that would result in firm entry, therefore, for the purpose of the outcome of the simulation, the level of barriers to entry does not need to be incorporated in the model.

The presence of barriers to exit can imply that firms stay on in the industry even when their profit levels have in effect become negative. Given an estimate of the level of the barriers to exit, we would simply not have firms leave unless their negative profits were higher (in absolute terms) than the level of the exit barrier. The results of the simulation in this case could be read by simply holding the number of firms constant or by allowing a smaller reduction in the number of firms exiting. We caution, however, that given that we are modelling a fixed cost shock in an oligoplistic framework, we will see no impacts on downstream prices and quantities unless one or more producers either exit or effectively stop competing in the production of at least some substances.

4 Examples

To illustrate the functioning of the model and the quantitative impact of particular fixed cost shocks we provide below a number of numeric illustrations for the model. The model is flexible enough to allow for both symmetric and asymmetric market structures. We start with numeric examples for markets with symmetric firms.

4.1 Symmetric firms

For market structures with symmetric firms we need to provide the following inputs for the model simulation:

- demand parameters for final demand
- variable costs and fixed costs for both tiers of the supply chain
- number of firms in each tier
- value of the fixed cost shock that will impact the upstream firms.

As results from our model we will have the following variables describing the initial equilibrium, the new equilibrium, and the corresponding percentage change:

- total output (given the assumption of the model, that one unit of input is required for each unit of output, the total output is identical in both tiers)
- individual output for each firm in each tier (identical across symmetric firms)
- equilibrium prices in each tier
- individual profits for each firm in each tier (identical across symmetric firms)
- percentage mark-ups in each tier.

4.1.1 Example 1 – a symmetric equilibrium with a large number of firms in both tiers

In this example we illustrate the impact of a change in fixed costs that is high enough to cause one of the firms in the upper tier of the market to exit. Even though we have a large number of firms on each tier of the market, the exit of just one firm has an impact on the equilibrium variables in both markets. Total output goes down by about 1/10 0f 1%. Equilibrium price goes up by 2.2% in the upper tier of the market, but by only 1.2% for the final demand. For the remaining firms upstream profits go up significantly while for the downstream firms profits fall somewhat.

Example 1						
INPUTS to the model						
	upstream	downstream		Demand parameters		
V. costs	0.1	0.1		Intercept	6	
F. costs	3.3	1.5		Slope	0.01	
FC change	0.14	---				
# of firms	30	40				
OUTPUTS of the simulation						
	Before		After		Percentage change	
	upstream	downstream	upstream	downstream	upstream	downstream
Total output	547.60	547.60	546.99	546.99	-0.1%	-0.1%
Price	0.29	0.52	0.29	0.53	2.2%	1.2%
# of firms	30	40	29	40	-3.3%	0.0%
Firm output	18.25	13.69	18.86	13.67	3.3%	-0.1%
Profits	0.12	0.37	0.21	0.37	81.0%	-1.1%
Mark-up (/p1)	35.7%	26.1%	36.5%	25.8%	2.2%	-1.3%
Abs. mark-up	0.19	0.14	0.19	0.14	3.3%	-0.1%

4.1.2 Example 2 – a symmetric equilibrium with a small number of firms upstream and a large number of firms downstream

In this example we assume that there is a large number of downstream producers but only a small number of upstream firms.

As a result of the increase in fixed costs, one of the upstream firms will leave the market. The impact of this on the variables of the model is:

- a 6% decrease in total output
- a 23% increase in upstream prices but only a 18.6% increase in the final prices, meaning that downstream produces absorb 4.4% of the price change
- a very significant increase in profits and in the level of mark-ups for the upstream producers
- individual outputs and profits both fall for the downstream firms.

Example 2						
INPUTS to the model						
	upstream	downstream		Demand parameters		
V. costs	0.1	0.1		Intercept	6	
F. costs	120	1.5		Slope	0.01	
FC change	12.26	0				
# of firms	4	30				
OUTPUTS of the simulation						
	Before		After		Percentage change	
	upstream	downstream	upstream	downstream	upstream	downstream
Total output	449.03	449.03	420.97	420.97	-6.3%	-6.3%
Price	1.26	1.51	1.55	1.79	23.0%	18.6%
# of firms	4	30	3	30	-25.0%	0.0%
Firm output	112.26	14.97	140.32	14.03	25.0%	-6.3%
Profits	10.22	0.74	71.20	0.47	596.8%	-36.6%
Mark-up (/p1)	76.8%	9.9%	81.0%	7.8%	5.4%	-21.0%
Abs. mark-up	1.16	0.15	1.45	0.14	25.0%	-6.3%

4.1.3 Example 3 – a symmetric equilibrium with a small number of firms in both tiers

In this example we assume a small number of firms in both tiers of the market.

As a result of the fixed cost shock we would see initially that one upstream firm would leave the market. As a result of this, however, the loss in relative market power for the downstream firms signifies that the current number of firms can no longer break-even. So at the new equilibrium we need that one downstream firm exits the market as well.

Example 3						
INPUTS to the model						
	upstream	downstream		Demand parameters		
V. costs	0.1	0.1		Intercept	6	
F. costs	100	80		Slope	0.01	
FC change	9.2	0				
# of firms	4	4				
OUTPUTS of the simulation						
	Before		After		Percentage change	
	upstream	downstream	upstream	downstream	upstream	downstream
Total output	371.20	371.20	348.00	348.00	-6.3%	-6.3%
Price	1.26	2.29	1.55	2.52	23.0%	10.1%
# of firms	4	4	3	4	-25.0%	0.0%
Firm output	92.80	92.80	116.00	87.00	25.0%	-6.3%
Profits	7.65	6.12	59.02	-4.31	671.7%	-170.4%
Mark-up (/p1)	50.7%	40.6%	57.5%	34.5%	13.5%	-14.9%
Abs. mark-up	1.16	0.93	1.45	0.87	25.0%	-6.3%

The table below describes the impact of moving from 3 firms in the upstream and 4 downstream to 3 firms in both tiers.

Example 3a						
INPUTS to the model						
	upstream	downstream		Demand parameters		
V. costs	0.1	0.1		Intercept	6	
F. costs	109.2	80		Slope	0.01	
FC change	0	0				
# of firms	3	4				
OUTPUTS of the simulation						
	Before		After		Percentage change	
	upstream	downstream	upstream	downstream	upstream	downstream
Total output	348.00	348.00	326.25	326.25	-6.3%	-6.3%
Price	1.55	2.52	1.55	2.74	0.0%	8.6%
# of firms	3	4	3	3	0.0%	-25.0%
Firm output	116.00	87.00	108.75	108.75	-6.3%	25.0%
Profits	59.02	-4.31	57.69	38.27	-2.3%	-987.8%
Mark-up (/p1)	57.5%	34.5%	53.0%	39.7%	-7.9%	15.1%
Abs. mark-up	1.45	0.87	1.45	1.09	0.0%	25.0%

This last table compares the initial situation where we had 4 firms in each tier with the final situation where we have 3 firms in each tier. In the present example, a fixed cost shock affecting only the upper tier of the market has an impact on the equilibrium number of firms in both tiers.

As we can see from the table below the impact of the fixed cost change can be summarised as follows:

- total output in the market goes down by 12%
- price for final consumers goes up by 19.6% but input price goes up by 23% meaning that the downstream tier absorbs 3.4% of the price change
- individual firms' output goes up by 17%
- individual firms' profits go up between 5 and 6 fold
- mark-ups go up in the upper tier and down in the lower tier.

Example 3b						
INPUTS to the model						
	upstream	downstream		Demand parameters		
V. costs	0.1	0.1		Intercept	6	
F. costs	100	80		Slope	0.01	
FC change	9.2	0				
# of firms	4	4				
OUTPUTS of the simulation						
	Before		After		Percentage change	
	upstream	downstream	upstream	downstream	upstream	downstream
Total output	371.20	371.20	326.25	326.25	-12.1%	-12.1%
Price	1.26	2.29	1.55	2.74	23.0%	19.6%
# of firms	4	4	3	3	-25.0%	-25.0%
Firm output	92.80	92.80	108.75	108.75	17.2%	17.2%
Profits	7.65	6.12	57.69	38.27	654.3%	525.4%
Mark-up (/p1)	50.7%	40.6%	53.0%	39.7%	4.5%	-2.0%
Abs. mark-up	1.16	0.93	1.45	1.09	25.0%	17.2%

4.2 Asymmetric firms

In this section we provide a couple of examples of the bilateral oligopoly model for the case where firms are asymmetric. Although our model is flexible enough to allow for any number of different firms in each tier, we have restricted the examples here to two groups of firms in each tier. We assume, for each tier, a group of larger firms (with higher fixed costs and lower variable costs) and a group of smaller firms.

We provide the results of the simulation for each type of firm on each tier.

4.2.1 Example 4 – an asymmetric equilibrium with a small number of firms in both tiers

In this example we assume 9 firms upstream of which 3 are large and 6 are small, and 10 firms downstream of which 2 are large and 8 are small.

As a result of the fixed cost shock, one of the smaller firms in the upstream tier will exit the market. As a result of this adjustment in the equilibrium number of firms, total output will decrease by 1.1% and price goes up 6.7% for the upstream tier and 3% for final users.

The profits of all firms in the industry go down but those of smaller firms in the upper tier of the market are affected the most, with a decrease of 28%. Larger firms see lower decreases in profits: 5% for those upstream and 9% for those downstream.

Mark-ups are reported as a percentage of the final price. Mark-ups reflect the "market power" of the firms. Larger firms are therefore able to charge higher mark-ups. Mark-ups are also required to cover the fixed portion of the firms' costs. Therefore an increase in fixed costs will typically be reflected in an increase in mark-ups. The operation of these forces is illustrated in the present example. Mark-ups increase upstream because there are fewer firms and because fixed costs are higher.

INPUTS to the model						
	upstream	downstream			Demand parameters	
V. costs - large	0.05	0.1			Intercept	6
V. costs - small	0.3	0.4			Slope	0.01
F. costs - large	40	40				
F. costs - small	10	12				
FC shock	7.15	0				
# of large firms	3	2				
# of small firms	6	8				
OUTPUTS of the simulation						
	Upstream			Downstream		
	before	after	pctg change	before	after	Pctg change
Total output	445.36	440.71	-1.1%	445.36	440.71	-1.1%
Price	0.76	0.81	6.7%	1.55	1.59	3.0%
# of large firms	3	3	0.0%	2	2	0.0%
# of small firms	6	5	-16.7%	8	8	0.0%
Firm output - large	64.64	69.29	7.2%	68.54	68.07	-0.7%
Firm output - small	41.91	46.57	11.1%	38.54	38.07	-1.2%
Profits - large	5.96	5.67	-4.8%	6.97	6.34	-9.1%
Profits - small	9.32	6.70	-28.1%	2.85	2.49	-12.5%
Mark-ups - large	46.0%	47.9%		44.3%	45.9%	
Mark-ups - small	29.8%	32.2%		24.9%	23.9%	

4.2.2 Example 5 – an asymmetric equilibrium with a large number of firms in both tiers

In this example we have 30 firms upstream and 45 firms downstream. 10 and 15 firms respectively are relatively large in each tier.

As a result of the fixed cost shock one of the small firms will exit the market. This will have a lower impact on the equilibrium variables of the model than in the previous example, as is natural since the number of firms is now considerably larger.

Total output goes down by only 0.1% and final price for users goes up by 0.6%.

Profits for the upstream firms go down significantly, particularly for the smaller firms. The impact is coming from the fixed costs shock which affects firms relatively more in a market that is more competitive because in these markets profits are generally lower to start with. The impact on profits of downstream firms is very small. This is mainly because there is no fixed cost shock downstream and all other effects are diluted over the large number of firms.

INPUTS to the model						
	upstream	downstream			Demand parameters	
V. costs - large	0.05	0.1			Intercept	6
V. costs - small	0.2	0.3			Slope	0.001
F. costs - large	40	10				
F. costs - small	14	2				
FC shock	3.40	0				
# of large firms	10	15				
# of small firms	20	30				
OUTPUTS of the simulation						
	Upstream			Downstream		
	before	after	pctg change	before	after	pctg change
Total output	5317.32	5313.04	-0.1%			
Price	0.33	0.34	1.3%	0.68	0.69	0.6%
# of large firms	10	10	0.0%	15	15	0.0%
# of small firms	20	19	-5.0%	30	30	0.0%
Firm output - large	275.07	279.35	1.6%	251.50	251.40	0.0%
Firm output - small	128.33	132.61	3.3%	51.50	51.40	-0.2%
Profits - large	37.35	36.37	-2.6%	53.25	53.20	-0.1%
Profits - small	2.83	0.57	-79.8%	0.65	0.64	-1.5%
Mark-ups - large	41.2%	41.6%		36.8%	43.9%	
Mark-ups - small	19.2%	19.7%		7.5%	7.5%	

4.3 Example 6 – a symmetric equilibrium with banning of substance(s)

As explained in the previous section under heading 3.6.1, we analyse in this example the potential quantitative impact on the main variables of the model as a result of a ban on the use of a substance that was uniquely supplied by one of the upstream firms. We assume, therefore, that, as the use of the substance is banned, the production of its former producer cesses and the firm consequently exits the market.

In addition, we assume that the loss of this substance reflects downstream in terms of either or both of the following: a) an increase in the costs that downstream producers face for producing an output that is equally valued by final users and b) a decrease in the valuation that final consumers attribute to the new final product.

We abstract, for this example, of shocks impacting fixed costs and focus solely on the impact of banning one substance. The MatLab code for this example can be found in Annex 4.

INPUTS to the model					
	upstream	downstream		Demand parameters	
V. costs	0.1	0.1		Intercept	6
F. costs	1	1		Slope	0.01
FC shock	0	0			
# of firms	20	20			

OUTPUTS of the simulation						
	Upstream			Downstream		
	before	After	pctg change	before	after	Pctg change
Total output	526.0771	511.0165	-2.9%			
Price	0.3762	0.3824	1.7%	0.7392	0.7379	-0.2%
# of firms	20	19		20	20	
Firm output	26.3039	26.8956	2.3%	26.3039	25.5508	-2.9%
Profits	6.2649	6.5954	5.3%	5.9189	5.5284	-6.6%

We note that, in this example, the banning of a substance can have quite strong impact because there are only 20 substances being used in the production of the final good. In a sector such as can coatings, where the number of substances used is much larger, the impact of banning one such substance would be correspondingly much smaller.

As we can see from the outcomes above, the banning of one substance causes a negative impact on final output. Final price is reduced slightly, however, this does not reflect a gain for consumers because the product is also valued less. Individual firm's output upstream go up, producing more of other substances (given that in our example substances are assumed to be largely substitutable – a different outcome would arise for the case where the banned substance does not have substitutes among the other substances) to replace to loss in production of the banned substance.

Individual firms output downstream goes down as do, more substantially, downstream firms' profits. In the example, upstream firms' profits go up. As we have seen, the impact on profits upstream in a situation such as this is ambiguous. There is a negative effect because demand valuation for the same output goes down but there is also a positive effect because one competitor has dropped out of the market. When the number of firms is relatively small, the latter effect tends to dominate.

5 Model simulation for the can coatings sector

In this section we explore the implications of the economic model for the analysis of the impact that a fixed cost shock in the can coatings sector can be expected to have in firms, both upstream and downstream.

There are alternative ways in which the model can be adapted to describe the can coatings sector. The study developed during this project has identified the following approximate characteristics for the can coatings sector:

- There are two main production tiers, on producing substances and coatings (upstream) and one producing cans (downstream).
- There are approximately 5 large firms in the upstream tier and 5 large and 35 small in the downstream tier.
- The output of the 35 small downstream firms adds up to about 10% of the total output at that tier.
- Profit margins in either tier do not exceed 2-3%.
- The total number of substances produced by upstream firms is about 500.

We have thus chosen to model a two-tier supply chain where the upstream tier comprises 5 large firms and the downstream tier comprises 5 large and 35 small firms. We have calibrated the variables so that in the downstream tier the total output of the 35 small firms is about 10% of the total output, while the total output of the 5 large firms corresponds to 90% of total output. We have also calibrated the other variables in the model to match the profit margins that were indicated to us as well as the estimated number of substances produced.

We note that, in order to keep our modelling from becoming overly cumbersome, we assume that the firms in each of the three groups (upstream large, downstream large and downstream small) are symmetric.

As we have explained, the economic model can capture effects from fixed cost shocks to the upstream firms only when we allow the fixed cost shocks to have an impact either on the number of firms operating upstream or on the number of substances produced by each firm. In the present case, since we have a supply chain with only 5 upstream firms, it appears excessive to allow a change in the number of firms from 5 to 4. It also goes against what we have come to expect from studying the industry and after the discussions with the industry experts.

As a result, we have instead decided to model the impact of the fixed cost shock through a decision to change the number of substances offered by each firm. Due to the assumed symmetry, each one of the 5 upstream firms produces a same number of substances. These firms have fixed costs that arise from their normal operations and they also have fixed costs that can be traced to producing the different types of substances. We assume that there is a component of the fixed costs that changes with the number of different substances that firms decide to produce. This is particularly suited to the modelling exercise at hand because the shock that we have in mind is a fixed cost shock that will impact firms on a 'per substance' basis.

On the demand, side we have assumed a demand function that values the final product more highly when the number of substances available is greater. This represents a reduced form approach to modelling the production constraints that a reduction in the number of available substances will impose on downstream producers, as well as the potentially reduced appeal that the industry outputs will have to final consumers.

The assumed functional form for the demand function is:

$$p = a\left(\frac{NS}{\alpha}\right)^{\gamma} - bQ\,,$$

where NS represents number of substances and alpha is used for scaling while gamma controls the impact on demand valuation of additional increases in the number of substances. Gamma is a number between 0 and 1 so that additional increases in substance variety have decreasing positive impact on corresponding demand valuations.

Upstream firms will choose the number of substances to produce as part of their profit maximising decisions. A number of factors will influence the optimal variety of substances to produce. These include demand conditions, cost conditions, and the number of competitors in each tier. In particular, the choice will depend on the fixed cost per substance that the firms face. If an initial equilibrium is disrupted by an increase in this fixed cost, the new profit maximising choice will imply a lowering of the number of substances produced.

This impact is illustrated in the simulation described below.

We assume that there is a shock affecting the 'per substance' fixed costs of upstream firms. The shock changes the per substance fixed costs from 0.07 to 0.071. This is about a 1.4% increase on per substance fixed costs.

As a result of the increase on the fixed costs per substances, upstream firms choose to lower the number of substances produced. In the event, this is a small decrease from 483 substances to 474.

This decrease in the number of substances offered has the impact of slightly lowering both the upstream and the downstream prices of the industry's output. This is a small decrease, of the order of one fifth of one percent.

Profits are predicted to go down both upstream and downstream. Upstream firms' profits are more affected than those of downstream firms because the fixed cost shock impacts them directly and they manage to pass along the impact of the shock only partially.

The smaller firms downstream will be more affected by this attempt from upstream firms to pass their increases in cost along the supply chain than the large ones. This is due to their relatively smaller market power.

INPUTS to the model						
	upstream	Down-stream			Demand parameters	
V. costs - large	0.05	0.05			Intercept	6
V. costs - small	-	0.81			Slope	0.005
FC per subst.	0.07					
FC - large	110	110			Alpha	500
FC - small	-	0.01			Gamma	1/10
FC per subst. shock	0.001	-				
# of large firms	5	5				
# of small firms	0	35				
OUTPUTS of the simulation						
	Upstream			Downstream		
	before	after	pctg change	before	after	pctg change
Total output	847.851	846.024	-0.22%	847.852	846.024	-0.22%
Price	0.919	0.917	-0.20%	1.740	1.738	-0.12%
# of substances	483	474	-1.86%			
Firm output - large	169.570	169.205	-0.22%	154.196	154.151	-0.03%
Firm output - small	-	-		2.196	2.151	-2.08%
Profits - large	3.554	3.076	-13.46%	8.882	8.812	-0.79%
Profits - small	-	-		0.014	0.013	-7.09%
AC large	0.898	0.899		1.682	1.681	
AC small	-	-		1.734	1.732	
Profit mg – large	2.33%	2.03%		3.43%	3.40%	
Profit mg – small				0.37%	0.35%	

The magnitude of the change in costs that we have assumed for this simulation is of the order of 1/3 of 1 percent of the original costs for the upstream firms. This relatively small shock has a small but noticeable impact along the supply chain. As a result of the assumed fixed cost shock we have the following effects:

a. The total number of substances that upstream firms choose to produce is predicted to go down by about 1/2 of a percentage point.

b. Upstream prices decrease by 0.2% and downstream prices by 0.1%.

c. Total output in the industry decreases 0.2%.

d. Profit margins decrease only very slightly for both the upstream and the downstream firms.

5.1 Sensitivity of the model to the assumed parameters

In this section we offer a brief discussion of how different parametric assumptions would potentially change the outcome of the simulation.

5.1.1 Costs parameters

All changes simulated as a result of the fixed costs shock are independent of the original fixed cost levels. Fixed costs do not impact equilibrium prices or quantity choices by the firms. The only impact of fixed costs is on initial estimates of profitability.

Changes in variable costs, on the other hand, will change both quantity decisions and equilibrium prices. For example, an increase in upstream variable costs from 0.05 per unit to 0.06, would change initial equilibrium slightly: higher prices, lower profits and equilibrium number of substances would be 482 instead of 483. But once we did the change in per substance fixed costs from 0.07 to 0.071 we would see all the same effects as in the original simulation – in particular, the number of substances would be reduced exactly by 9, to 473.

Changes in the per substance fixed cost are likely to have a more dramatic effect in the outcomes of the simulation as this is one of the crucial variables. Since we are starting from a position of 500 substances, even a small increase in substance fixed cost can cause a large change in the optimal number of substances produced upstream.

For example, a change from per substance fixed cost from 0.07 to 0.14 would change the optimal number of substances from 483 to 200. A subsequent shock of 0.001 would then have a substantially reduced impact over the variables of the model, compared with the shock we introduced when the number of substances was 483. This, however, is not surprising since with a smaller number of substances the impact of the shock on costs per substance has naturally to be smaller. In addition, our study of the industry leads us to an estimate closer to 500 substances.

5.2 Demand parameters

The study of the sensitivity of the results to alternative assumptions for the demand parameters is particularly important for assessing the robustness of the simulation results herein. We note, however, that no attempt to estimate demand functions has been made and, consequently, we will not be able to put forward strong arguments either in favour or against particular specifications.

Demand elasticity parameters

Ignoring, for a moment, the parameters determining demand valuation for variety of substances, demand elasticity in the linear demand function that we have used for this simulation is given by:

$$\varepsilon = \frac{dQ}{dp}\frac{p}{Q} = \left(-\frac{1}{b}\right)\frac{a-bQ}{Q} = -\frac{a-bQ}{bQ} = -\left(\frac{a}{bQ}-1\right)$$

A change of the demand intercept:

An increase in 'a', the intercept of the demand curve, will shift all variables up. Output, prices, profits and equilibrium number of substances. However, we observe that once a shock on per substance fixed costs is introduced, the qualitative impact of this shock on the main variables is unchanged.

A change of the demand slope:

A decrease in 'b' corresponds to a decrease in the 'price sensitivity' of demand. It has similar impact to an increase in 'a' and the conclusions are as above.

A change in the demand elasticity:

By manipulating both parameters a and b of the demand function we are able to investigate, for example, what the impact in our simulation would be if demand were, say, 15% less elastic.[8] This will change the initial equilibrium considerably. Lower elasticity of demand makes upstream sellers better off, as expected. They are able to sell higher quantities of output with less impact on prices. The equilibrium number of substances also increases substantially to 683.

On the downstream market it has a curious impact – small firms are better off but large firms are worse off. This is due to the fact that small firms will increase their output substantially given the higher prices and given that because they are small they do not see the benefit of restricting output in order to keep prices high.

We now perform our simulated increase in fixed costs per substance and investigate the impact of this change in a world where demand elasticity is lower than the one we initially studied. A summary of the results is presented in the table below.

	Upstream			Downstream			CHANGES	
	Before	After		Before	After		UP	DOWN
Aggregate output	815.8335	815.832					-0.19%	
# of substances	683	671					-1.76%	
Price	1.388	1.3854		2.2661	2.2632		-0.19%	-0.13%
Output large	163.1667	162.8502		103.5208	103.4813		-0.19%	-0.04%
Output small				8.5208	8.4813			-0.46%
Profits large	60.5018	59.8246		-24.2675	-24.333		-1.12%	-0.27%
Profits small				0.5708	0.5655			-0.93%

[8] We do this in a way so that the new demand function intercepts the old one approximately at the point of the original equilibrium. This corresponds to a linear demand function that is "more vertical" than the original one but that passes through the initial equilibrium price and output pair.

When we compare these results with those obtained in our original simulation, we conclude that the impact of an increase in the fixed cost per substance is roughly identical. This is more noticeable in terms of absolute changes rather than percent changes – percent changes can be misleading here since for some cases we start with base values that are quite different.

Varieties' valuation parameters

A change in gamma represents a change in how extra varieties of substances are valued. For example, changing gamma from 1/10 to 1/20 implies that the valuation for additional varieties of substances decreases less slowly. The result is that equilibrium happens at considerably lower number of substances. But, as with the other changes that we have considered, a similar shock in terms of fixed cost per substance, has a similar impact in all variables of the model.

The MatLab code for the model simulation presented above can be found in Annex 3. This enables the readers to do their own experiments with different parametrisations of the model.

Annex 1 :

Matlab code for the symmetric model

In this annex we make available the Matlab code for the first table in example 3.

```
%upstream L2 large firms S2 small firms
L2=3;
S2=6;
for j=1:L2
   v2(j)=0.05;
   F2(j)=40;
end
for j=L2+1:L2+S2
   v2(j)=0.3;
   F2(j)=10;
end
%downstream L1 large firms S1 small firms
L1=2;
S1=8;
for j=1:L1
   v1(j)=0.1;
   F1(j)=40;
end
for j=L1+1:L1+S1
   v1(j)=0.4;
   F1(j)=12;
end
%demand for final product
a1=6; b1=0.01;
n1=length(v1);
n2=length(v2);
avg_v1=mean(v1);
avg_v2=mean(v2);

Q2 = n1*n2 / (b1*(1+n1)*(1+n2)) *(a1-avg_v1-avg_v2);
p2 = a1 - avg_v1 -b1*(1+n1)/n1*Q2;
Q1 = n1 / ((1+n1)*b1) * (a1 - avg_v1 - p2);
p1 = a1 - b1*Q1;
for j=1:n1
   q1(j)=(a1 - v1(j) - p2)/b1 - Q1;
  pi1(j)=(p1 - v1(j) - p2)*q1(j) - F1(j);
end
for j=1:n2
   q2(j)=(n1/(b1*(1+n1)))*(a1 - avg_v1 - v2(j)) - Q2;
  pi2(j)=(p2 - v2(j))*q2(j) - F2(j);
end

P=[p2,p1];
Q=[Q1,Q2];
T1=[q1',pi1'];
T2=[q2',pi2'];
```

```
if min(pi2)>0
   fcshock=1.2*min(pi2);
   q2after(n2)=0;
   pi2after(n2)=0;
   F2after(n2)=0;
   n2after=n2-1;
   avg_v2after=(sum(v2)-v2(n2))/(n2-1);
else
   fcshock=0
   n2after=n2;
   avg_v2after=avg_v2;
end
for j=1:n2
   F2after(j)=F2(j)+fcshock;
end
for j=1:n1
   F1after(j)=F1(j);
end
%one of the smaller firms exits
Q2after = n1*n2after / (b1*(1+n1)*(1+n2after)) *(a1-avg_v1-avg_v2after);
p2after = a1 - avg_v1 -b1*(1+n1)/n1*Q2after;
Q1after = n1 / ((1+n1)*b1) * (a1 - avg_v1 - p2after);
p1after = a1 - b1*Q1after;
for j=1:n1
      q1after(j)=(a1 - v1(j) - p2after)/b1 - Q1after;
     pi1after(j)=(p1after - v1(j) - p2after)*q1after(j) - F1(j);
end
for j=1:n2after
      q2after(j)=(n1/(b1*(1+n1)))*(a1 - avg_v1 - v2(j)) - Q2after;
     pi2after(j)=(p2after - v2(j))*q2after(j) - F2after(j);
end

Pafter=[p2after,p1after];
Qafter=[Q1after,Q2after];
T1after=[q1after(2),pi1after(2)];
T2after=[q2after(2),pi2after(2)];

Q2change = (Q2after-Q2)/Q2;
p2change = (p2after-p2)/p2;
Q1change = (Q1after-Q1)/Q1;
p1change = (p1after-p1)/p1;
for j=1:n1
      q1change(j)=(q1after(j)-q1(j))/q1(j);
     pi1change(j)=(pi1after(j)-pi1(j))/pi1(j);
end
for j=1:n2
      q2change(j)=(q2after(j)-q2(j))/q2(j);
     pi2change(j)=(pi2after(j)-pi2(j))/pi2(j);
end
```

```
Pchange=[p2change,p1change];
Qchange=[Q1change,Q2change];
T1change=[q1change(2),pi1change(2)];
T2change=[q2change(2),pi2change(2)];
n2change=(n2after-n2)/n2;
EE = -(1/b1)*(p1/Q1);
EEafter = -(1/b1)*(p1after/Q1after);
ELAST = [EE EEafter];
mgnupl = (p2-v2(1))/p1;
mgnupafterl = (p2after-v2(1))/p1after;
mgndownl = (p1-v1(1)-p2)/p1;
mgndownafterl = (p1after-p2after-v2(1))/p1after;
mgnups = (p2-v2(n2-1))/p1;
mgnupafters = (p2after-v2(n2-1))/p1after;
mgndowns = (p1-v1(n1-1)-p2)/p1;
mgndownafters = (p1after-p2after-v1(n1-1))/p1after;

INPUTS = [      v2(1)       v1(1);
            v2(L2+1)    v1(L1+1);
            F2(1)       F1(1);
            F2(L2+1)    F1(L1+1);
            fcshock     0;
            L2          L1;
            S2          S1      ];

OUTPUTS = [     p2 p2after p2change p1 p1after p1change;
            L2 L2 0 L1 L1 0;
            S2 S2-1 -1/S2 S1 S1 0;
            q2(1) q2after(1) q2change(1) q1(1) q1after(1) q1change(1);
            q2(L2+1)      q2after(L2+1)      q2change(L2+1)      q1(L1+1)      q1after(L1+1)
q1change(L1+1);
            pi2(1) pi2after(1) pi2change(1) pi1(1) pi1after(1) pi1change(1);
            pi2(L2+1)     pi2after(L2+1)     pi2change(L2+1)     pi1(L1+1)     pi1after(L1+1)
pi1change(L1+1);
            mgnupl mgnupafterl 0 mgndownl mgndownafterl 0;
            mgnups mgnupafters 0 mgndowns mgndownafters 0 ];

format long
AGGOUTPUT = [ Q2 Q2after Q2change Q1 Q1after Q1change]

format short
fprintf('INPUTS:\n')
disp(INPUTS)
fprintf('OUTPUTS:\n')
disp(OUTPUTS)
```

Annex 2

Matlab code for the asymmetric model

This annex contains the Matlab code used to generate example 5.

```
%upstream L2 large firms S2 small firms
L2=10;
S2=20;
for j=1:L2
   v2(j)=0.05;
   F2(j)=40;
end
for j=L2+1:L2+S2
   v2(j)=0.2;
   F2(j)=14;
end
%downstream L1 large firms S1 small firms
L1=15;
S1=30;
for j=1:L1
   v1(j)=0.1;
   F1(j)=10;
end
for j=L1+1:L1+S1
   v1(j)=0.3;
   F1(j)=2;
end
%demand for final product
a1=6; b1=0.001;
n1=length(v1);
n2=length(v2);
avg_v1=mean(v1);
avg_v2=mean(v2);
Q2 = n1*n2 / (b1*(1+n1)*(1+n2)) *(a1-avg_v1-avg_v2);
p2 = a1 - avg_v1 -b1*(1+n1)/n1*Q2;
Q1 = n1 / ((1+n1)*b1) * (a1 - avg_v1 - p2);
p1 = a1 - b1*Q1;
for j=1:n1
   q1(j)=(a1 - v1(j) - p2)/b1 - Q1;
  pi1(j)=(p1 - v1(j) - p2)*q1(j) - F1(j);
end
for j=1:n2
   q2(j)=(n1/(b1*(1+n1)))*(a1 - avg_v1 - v2(j)) - Q2;
  pi2(j)=(p2 - v2(j))*q2(j) - F2(j);
end
P=[p2,p1];
Q=[Q1,Q2];
T1=[q1',pi1'];
T2=[q2',pi2'];
if min(pi2)>0
   fcshock=1.2*min(pi2);
   q2after(n2)=0;
```

```
   pi2after(n2)=0;
   F2after(n2)=0;
   n2after=n2-1;
   avg_v2after=(sum(v2)-v2(n2))/(n2-1);
else
   fcshock=0
   n2after=n2;
   avg_v2after=avg_v2;
end
for j=1:n2
   F2after(j)=F2(j)+fcshock;
end
for j=1:n1
   F1after(j)=F1(j);
end
%one of the smaller firms exits
Q2after = n1*n2after / (b1*(1+n1)*(1+n2after)) *(a1-avg_v1-avg_v2after);
p2after = a1 - avg_v1 -b1*(1+n1)/n1*Q2after;
Q1after = n1 / ((1+n1)*b1) * (a1 - avg_v1 - p2after);
p1after = a1 - b1*Q1after;
for j=1:n1
      q1after(j)=(a1 - v1(j) - p2after)/b1 - Q1after;
     pi1after(j)=(p1after - v1(j) - p2after)*q1after(j) - F1(j);
end
for j=1:n2after
      q2after(j)=(n1/(b1*(1+n1)))*(a1 - avg_v1 - v2(j)) - Q2after;
     pi2after(j)=(p2after - v2(j))*q2after(j) - F2after(j);
end

Pafter=[p2after,p1after];
Qafter=[Q1after,Q2after];
T1after=[q1after(2),pi1after(2)];
T2after=[q2after(2),pi2after(2)];
Q2change = (Q2after-Q2)/Q2;
p2change = (p2after-p2)/p2;
Q1change = (Q1after-Q1)/Q1;
p1change = (p1after-p1)/p1;
for j=1:n1
      q1change(j)=(q1after(j)-q1(j))/q1(j);
     pi1change(j)=(pi1after(j)-pi1(j))/pi1(j);
end
for j=1:n2
      q2change(j)=(q2after(j)-q2(j))/q2(j);
     pi2change(j)=(pi2after(j)-pi2(j))/pi2(j);
end
Pchange=[p2change,p1change];
Qchange=[Q1change,Q2change];
T1change=[q1change(2),pi1change(2)];
T2change=[q2change(2),pi2change(2)];
```

```
n2change=(n2after-n2)/n2;
EE = -(1/b1)*(p1/Q1);
EEafter = -(1/b1)*(p1after/Q1after);
ELAST = [EE EEafter];
mgnupl = (p2-v2(1))/p1;
mgnupafterl = (p2after-v2(1))/p1after;
mgndownl = (p1-v1(1)-p2)/p1;
mgndownafterl = (p1after-p2after-v2(1))/p1after;
mgnups = (p2-v2(n2-1))/p1;
mgnupafters = (p2after-v2(n2-1))/p1after;
mgndowns = (p1-v1(n1-1)-p2)/p1;
mgndownafters = (p1after-p2after-v1(n1-1))/p1after;
% display format for text tables
INPUTS = [    v2(1)     v1(1);
        v2(L2+1)  v1(L1+1);
        F2(1)     F1(1);
        F2(L2+1)  F1(L1+1);
        fcshock   0;
        L2        L1;
        S2        S1     ];

OUTPUTS = [    p2 p2after p2change p1 p1after p1change;
        L2 L2 0 L1 L1 0;
        S2 S2-1 -1/S2 S1 S1 0;
        q2(1) q2after(1) q2change(1) q1(1) q1after(1) q1change(1);
        q2(L2+1)    q2after(L2+1)    q2change(L2+1)    q1(L1+1)    q1after(L1+1)
q1change(L1+1);
        pi2(1) pi2after(1) pi2change(1) pi1(1) pi1after(1) pi1change(1);
        pi2(L2+1)    pi2after(L2+1)    pi2change(L2+1)    pi1(L1+1)    pi1after(L1+1)
pi1change(L1+1);
        mgnupl mgnupafterl 0 mgndownl mgndownafterl 0;
        mgnups mgnupafters 0 mgndowns mgndownafters 0 ];

format long
AGGOUTPUT = [ Q2 Q2after Q2change Q1 Q1after Q1change]

format short
fprintf('INPUTS:\n')
disp(INPUTS)
fprintf('OUTPUTS:\n')
disp(OUTPUTS)
```

Annex 3

MatLab code for the final model simulation

```
%demand parameters
b = 0.005;
aa = 6;

%upstream L2 large firms S2 small firms
L2=3;
S2=2;

% firms choose number of substances to produce
% fixed costs increase with number of substances
% demand valuation increases with number of substances
% we will assume symmetry w.r.t. these decisions
% i.e. all firms choose the same number of substances

FCps = 0.07;

for NS = 1:1500;

if L2>0
   for j=1:L2
      v2(j)=0.05;
      F2(j)=110+FCps*NS;
   end
end

if S2>0
   for j=L2+1:L2+S2
      v2(j)=0.05;
      F2(j)=110+FCps*NS;
   end
end

%downstream L1 large firms S1 small firms

L1=5;
S1=35;

if L1>0
        for j=1:L1
      v1(j)=0.05;
      F1(j)=110;
        end
end

if S1>0
        for j=L1+1:L1+S1
      v1(j)=0.81;
      F1(j)=0.01;
```

```
        end
end



%demand for final product
a1 = aa*((NS/500)^(1/10)); b1 = b;

n1=length(v1);
n2=length(v2);

avg_v1=mean(v1);
avg_v2=mean(v2);

%equilibrium prices and output

Q2 = n1*n2 / (b1*(1+n1)*(1+n2)) *(a1-avg_v1-avg_v2);
p2 = a1 - avg_v1 -(1+n1)/n1*Q2*b1;
Q1 = n1 / ((1+n1)*b1) * (a1 - avg_v1 - p2);
p1 = a1 - Q1*b1;

% per firm output and profits

for j=1:n1
   q1(j)=(a1 - v1(j) - p2)/b1 - Q1;
  pi1(j)=(p1 - v1(j) - p2)*q1(j) - F1(j);
end

for j=1:n2
   q2(j)=(n1/(b1*(1+n1)))*(a1 - avg_v1 - v2(j)) - Q2;
  pi2(j)=(p2 - v2(j))*q2(j) - F2(j);
end

pi2NS(NS)=pi2(1);

end

%plot (pi2NS)

[pi2NSmax,NSmax] = max (pi2NS);

NS = NSmax

clear v2 F2

if L2>0
   for j=1:L2
      v2(j)=0.05;
      F2(j)=110+FCps*NSmax;
```

```
    end
end

if S2>0
    for j=L2+1:L2+S2
        v2(j)=0.05;
        F2(j)=110+FCps*NSmax;
    end
end

%downstream L1 large firms S1 small firms

clear Q2 p2 Q1 p1 a1

a1 = aa*((NS/500)^(1/10));

Q2 = n1*n2 / (b1*(1+n1)*(1+n2)) *(a1-avg_v1-avg_v2);
p2 = a1 - avg_v1 -(1+n1)/n1*Q2*b1;
Q1 = n1 / ((1+n1)*b1) * (a1 - avg_v1 - p2);
p1 = a1 - Q1*b1;


clear q1 pi1 q2 pi2

for j=1:n1
    q1(j)=(a1 - v1(j) - p2)/b1 - Q1;
   pi1(j)=(p1 - v1(j) - p2)*q1(j) - F1(j);
end

for j=1:n2
    q2(j)=(n1/(b1*(1+n1)))*(a1 - avg_v1 - v2(j)) - Q2;
   pi2(j)=(p2 - v2(j))*q2(j) - F2(j);
end

format short


OUTPUTS = [     p2  p1 ;
                q2(1) q1(1)
                q2(L2+1) q1(L1+1);
                pi2(1) pi1(1);
                pi2(L2+1) pi1(L1+1);]


elast = -(a1 - b1*Q1)/(b1*Q1)
```

Annex 4

MatLab code for the banned substance example

```
%upstream
for j=1:20
   v2(j)=0.1;
   F2(j)=1;
end

%downstream
for j=1:20
   v1(j)=0.1;
   F1(j)=1;
end


n1=length(v1);
n2=length(v2);

%demand
gamma=1/2;
a1=6*(n2/20)^(gamma); b1=0.01;

avg_v1=mean(v1);
avg_v2=mean(v2);

Q2 = n1*n2 / (b1*(1+n1)*(1+n2)) *(a1-avg_v1-avg_v2);
p2 = a1 - avg_v1 -b1*(1+n1)/n1*Q2;
Q1 = n1 / ((1+n1)*b1) * (a1 - avg_v1 - p2);
p1 = a1 - b1*Q1;

for j=1:n1
   q1(j)=(a1 - v1(j) - p2)/b1 - Q1;
  pi1(j)=(p1 - v1(j) - p2)*q1(j) - F1(j);
end

for j=1:n2
   q2(j)=(n1/(b1*(1+n1)))*(a1 - avg_v1 - v2(j)) - Q2;
  pi2(j)=(p2 - v2(j))*q2(j) - F2(j);
end


if pi2(1)>0
   fcshock=0;
   n2after=n2-1;
else
   fcshock=0;
   n2after=n2;
end

for j=1:n2
```

```
   F2after(j)=F2(j)+fcshock;
end
for j=1:n1
   F1after(j)=F1(j);
end

a1after=6*(n2after/20)^(gamma); b1=0.01;

Q2after = n1*n2after / (b1*(1+n1)*(1+n2after)) *(a1after-avg_v1-avg_v2);
p2after = a1after - avg_v1 -b1*(1+n1)/n1*Q2after;
Q1after = n1 / ((1+n1)*b1) * (a1after - avg_v1 - p2after);
p1after = a1after - b1*Q1after;

for j=1:n1
       q1after(j)=(a1after - v1(j) - p2after)/b1 - Q1after;
      pi1after(j)=(p1after - v1(j) - p2after)*q1after(j) - F1(j);
end

for j=1:n2after
       q2after(j)=(n1/(b1*(1+n1)))*(a1after - avg_v1 - v2(j)) - Q2after;
      pi2after(j)=(p2after - v2(j))*q2after(j) - F2after(j);
end

Q2change = (Q2after-Q2)/Q2;
p2change = (p2after-p2)/p2;
Q1change = (Q1after-Q1)/Q1;
p1change = (p1after-p1)/p1;

for j=1:n1
       q1change(j)=(q1after(j)-q1(j))/q1(j);
      pi1change(j)=(pi1after(j)-pi1(j))/pi1(j);
end

for j=1:n2after
       q2change(j)=(q2after(j)-q2(j))/q2(j);
      pi2change(j)=(pi2after(j)-pi2(j))/pi2(j);
end

n2change=(n2after-n2)/n2;

inprow1 = [v2(2) v1(2) ; F2(2) F1(2) ; fcshock 0];

row1 = [Q2 Q1 Q1after Q1after Q1change Q1change];
row2 = [p2 p1 p2after p1after p2change p1change];
row3 = [n2 n1 n2after n1 n2change 0];
row4 = [q2(2) q1(2) q2after(2) q1after(2) q2change(2) q1change(2)];
row5 = [pi2(2) pi1(2) pi2after(2) pi1after(2) pi2change(2) pi1change(2)];

format short
```

```
results = [row1 ; row2 ; row3 ; row4 ; row5];

fprintf('INPUTS vcup vcdown FCup FCdown FC-shock:\n')
disp(inprow1)
fprintf('RESULTS:\n')
disp(results)
```