Fondazione Eni Enrico Mattei

Introducing Imperfect Competition in CGE Models: Technical Aspects and Implications

Roberto Roson

NOTA DI LAVORO 3.2006

JANUARY 2006

CCMP – Climate Change Modelling and Policy

Roberto Roson, *Dipartimento di Scienze Economiche, Università Ca' Foscari diVenezia*

Introducing Imperfect Competition in CGE Models: Technical Aspects and Implications

Summary

This paper considers the technical aspects and the consequences, in terms of simulation results and policy assessment, of introducing imperfect competition in a CGE model. The modifications to the standard CGE framework needed to model imperfect competition in some industries are briefly discussed. Next, the paper discusses whether, how much and why, those changes may affect the qualitative output of a typical simulation experiment. It is argued that technical choices made in designing the model structure may have a significant impact on the model behavior. This is especially evident when the output of the model, under an imperfect competition closure, is compared with that obtained under a standard closure, assuming perfect competition. As an illustration, a scenario of agricultural trade liberalization under alternative market structures is analyzed.

Keywords: Computable general equilibrium models, Imperfect competition, Oligopolistic models, Economies of scale, Empirical industrial organization, Agriculture, Trade liberalization, Trade policy

JEL Classification: D58, F12, L16

This study is part of a project on economic modeling of climate change impacts, involving the Abdus Salam International Centre for Theoretical Physics (Trieste, Italy), the Fondazione Eni Enrico Mattei (Italy) and Hamburg University. Financial support from MURST (PRIN 2003) and the University of Genoa is gratefully acknowledged.

Address for correspondence:

Roberto Roson
Dipartimento di Scienze Economiche
Università Ca’ Foscari di Venezia
Cannaregio S.Giobbe 873
30121 Venezia
Italy
E-mail: roson@unive.it

Introducing Imperfect Competition in CGE Models: Technical Aspects and Implications

With an Illustration about Trade Liberalization in Agriculture

Roberto Roson*

Abstract

This paper considers the technical aspects and the consequences, in terms of simulation results and policy assessment, of introducing imperfect competition in a CGE model. The modifications to the standard CGE framework needed to model imperfect competition in some industries are briefly discussed. Next, the paper discusses whether, how much and why, those changes may affect the qualitative output a typical simulation experiment. It is argued that technical choices made in designing the model structure may have a significant impact on the model behavior. This is especially evident when the output of the model, under an imperfect competition closure, is compared with that obtained under a standard closure, assuming perfect competition. As an illustration, a scenario of agricultural trade liberalization under alternative market structures is analyzed.

JEL Codes: D58, F12, L16.

Keywords: Computable General Equilibrium Models, Imperfect Competition, Oligopolistic Models, Economies of Scale, Empirical Industrial Organization, Agriculture, Trade Liberalization, Trade Policy.

1 Introduction

The standard Computable General Model (CGE) is based on typical Walrasian hypotheses: perfect competition and price-taking, market clearing, free entry/exit and zero (extra) profits. However, a number of CGE models now embed market imperfection features, like price-setting and market power in some industries (since the seminal work by Harris (1984)), especially in the field of trade policy analysis, where imperfect competition is often associated with the presence of economies of scale (Harrison, Rutherford and Tarr(1997)).

Introducing imperfect competition in a CGE is not too difficult. However, a number of critical choices have to be made, having important consequences on simulation results and their interpretations. This is because there is not a single (or "right") way

*Dipartimento di Scienze Economiche, Università Ca' Foscari di Venezia, Cannaregio S.Giobbe 873, 30121 Venezia Italy. E-mail: roson@unive.it.

of accommodating market imperfections, some approximations are unavoidable, and simulations are carried out in a second-best context.

First of all, there are many models of oligopolistic market. Key differences regard assumptions about strategic behaviour, expectations and market entry. Additional assumptions regard price discrimination, product differentiation, etc. All these issues are not specific to the CGE world, but normally arise in Industrial Organization. Furthermore, there are additional issues associated with the translation of partial equilibrium concepts in a general equilibrium context, like the computation of the perceived demand elasticity in mark-up equations.

Extra data is needed to calibrate a CGE model under imperfect competition. This information is not (fully) available, especially at the aggregation level of CGE models, and other ad hoc assumptions need to be imposed, like symmetry among firms within an industry.

Given the multiplicity of options available for implementing imperfect competition, it is remarkable that most papers describing CGE models with market power in some industries do not provide an adequate description of the methodology adopted. This may suggest that there exist a standard procedure, or that the estimation of IC parameters is a (boring) technical issue, with little impact on the overall qualitative behaviour of the model. Unfortunately, this is not at all true.

This paper discuss some technical and conceptual issues associated with the introduction of imperfect competition in a CGE model. We illustrate the main points by considering a typical simulation exercise. This exercise simulates agricultural trade liberalization in Europe, comparing a standard CGE model closure with an alternative one, in which imperfect competition is introduced in some industries. Liberalization in agricultural markets is a much discussed topic, especially in relation with the Doha round of world trade agreements and the CAP reform in the EU. Although we aim at giving a flavour of realism to the exercise, this has not been designed for policy assessment, but only to illustrate the implications of adding imperfect competition in a "typical" CGE application. Nonetheless, some interesting points emerge.

The paper is organized as follows. In the next section, technical aspects of implementation of IC features in a CGE model are discussed. The following section address the question of whether, how much and why, the output of a simulation under an IC closure could differ from the one obtainable under a standard closure. The fourth section introduces the illustrative simulation exercise, and compares the results under alternative market structures. Some concluding remarks are drawn in a final section.

2 Introducing Imperfect Competition: Technical Aspects

2.1 The Perceived Elasticity of Demand

Despite the fact that oligopolistic models are many, price setting is always based on mark-up rules like:

$$p = \left(1 - \frac{1}{\epsilon}\right)^{-1} mc \tag{1}$$

where *mc* is the marginal cost, *p* is the price and ϵ is the *perceived* price elasticity of demand. Perceived elasticity means the percentage change in the demanded quantity which is supposed to take place after a percentage change in price. If there is only one firm in a industry, this coincides with the industry demand elasticity. If not, the perceived elasticity embodies assumptions about the other competitors' reaction to a change in the price of the specific price setting firm (conjectural variation).

In a standard CGE model with perfect competition, constant returns to scale imply that average costs equal marginal costs, and the zero profit condition can be simply stated as $p = mc = ac$. This condition is replaced by 1 in an imperfectly competitive closure. So one question is: which value should be used for the perceived elasticity parameter?

There are many elasticity parameters in a CGE model. However, these refer to *elasticities of substitution*, not to elasticities of demand. Most CGE models use nested combinations of CES functions to model substitution possibilities in production and final demand (either directly or through the special cases of Cobb-Douglas, Leontief or LES functions).

For a simple two-inputs aggregate, a CES function looks like:

$$y = \left(a_1 x_1^{\frac{\sigma-1}{\sigma}} + a_2 x_2^{\frac{\sigma-1}{\sigma}}\right)^{\frac{\sigma}{\sigma-1}} \tag{2}$$

where $\sigma = -\frac{\partial(x_i/x_j)}{\partial(p_i/p_j)} \frac{(p_i/p_j)}{(x_i/x_j)}$ is the (constant) elasticity of substitution.

It is well known that functions like 2 give raise to demand functions like:

$$x_i = A_i y \left(\frac{p_i}{p_y}\right)^{-\sigma} \tag{3}$$

where $A_i$is a scaling factor, and $p_y$is a price index for the aggregate output *y*:

$$p_y = \frac{p_1 x_1^* + p_2 x_2^*}{y} = p_1 \alpha_1^* + p_2 \alpha_2^* \tag{4}$$

where the asterisk indicates optimally chosen (cost-minimizing) inputs or input-output shares (α).

Equations like 3 can be used to directly estimate the industry elasticity of demand. However, the methodology used in CGE applications is not uniform, because of the presence, or absence, of some "hidden assumptions", which we briefly discuss here below.

Hidden Assumption #1 (HA1): Aggregate quantity does not depend on input prices.

In other words, the aggregate *y* (industry output, utility, intermediate composite) is taken as given when the demand elasticity is computed. This is a standard assumption in partial equilibrium analyses, but it would not be consistent with a general equilibrium formulation. In a general equilibrium, all markets are interlinked, and it is not generally true that *y* stays constant when even one single input price changes. Nonetheless, almost all CGE implementations assume this effect to be small and negligible. Hoffman (1999) proposes an alternative, empirical technique, in which standard CGE models are used to numerically estimate the true elasticity value (by simulating marginal price changes). This approach, however, may be problematic when there are many imperfectly competitive industries, as the simultaneous estimation of several elasticity parameters poses a number of technical difficulties.[1]

Hidden Assumption #2 (HA2): The aggregate price index does not significantly change when a single input price changes.

From 4 it is clear that, on the basis of the envelop theorem:

$$\frac{\partial p_y}{p_y} = s_i \frac{\partial p_i}{p_i} \tag{5}$$

where $s_i = \frac{p_i \alpha_i}{p_y}$ is a cost share parameter.

The effect on the price index of a price change for input *i* can be neglected only if $s_i \simeq 0$. In this case, substitution and demand elasticities coincide. This type of assumption has been adopted in most applications of the Spence-Dixit-Stiglitz model (e.g., Fujita, Krugman and Venables (1999)), and in a few CGE models (e.g., Swaminathan and Hertel (1997)). In the more general case, if HA1 holds:

$$\epsilon_i = \sigma - s_i \sigma \tag{6}$$

Notice that the elasticity ϵ_i may easily be lower than one. This may happen if the substitution elasticity σ is also lower than one, as it is often the case, and/or if the market share $s_i$is close to one (e.g., domestic products in domestic markets, in large economies). But if the elasticity ϵ_i is lower than one, it cannot be directly used in a mark-up equation like 1, as it would be for a monopolistic firm.[2]

Very often, CES functions are nested. For example, a CES function could be used to model substitutability among primary factors, and another one between aggregate value added and aggregate intermediate inputs. To illustrate how 6 has to be changed for nested CES structures, suppose that the aggregate composite *y* is itself an input to a higher level aggregate *z*. In this case:

$$\epsilon_i = \sigma_y (1 - s_i) + \sigma_z s_i (1 - s_y) \tag{7}$$

where the subscripts indicate the relevant substitution elasticity or cost share parameter.[3]

In CGE models, firms are assumed to be active in many markets: intermediate inputs, final consumption, investment goods, etc., of *each* region. If there are *r* regions,

[1]This is because elasticity values for all industries are needed to compute the equilibrium after a marginal change in one price. In other words, all elasticity values are interdependent, and should therefore be estimated simultaneously.

[2]This is a direct consequence of assumption HA1. For example, if one factor is sold to an industry with Leontief production structure, both demand and substitution elasticities would be zero. A profit maximizing firm would then set the price of the factor to infinity. But, when the factor price gets large, also the industrial price rises, reducing the industry output and the indirect demand for the factor. This effect is not taken into account when HA1 is adopted.

[3]Under HA2 we still have, even for nested CES structures: $\epsilon_i = \sigma_y$.

m industries, *k* sectors of final demand, there are *r(m+k)* markets. Since there are firms in *rm* industries, and if firms in each industry are assumed to be symmetric, there could be as much as $r^2m(m+k)$ price-setting equations like 1. This amount to assuming that firms can discriminate and apply different prices to different markets.

A convenient alternative hypothesis is ruling out price discrimination. In this case, there would be a single industry price, like in standard CGE models. Determining the global industry elasticity would then amount to determining the demand elasticity for a non-discriminating, multi-market monopoly. It is straightforward to show that:

$$\epsilon = \sum_i z_i \epsilon_i \tag{8}$$

where the index *i* refers to the different markets, and z_i is the *market* (quantity) share in the total output of the industry.

Notice that market elasticity is given by a linear combination of elasticities of substitutions, where factors are derived from cost shares, whereas total industry elasticity is given by a linear combination of market elasticities, where factors are market shares.

Equations like 7 and 9 can be used to estimate the market price elasticity. This is not, however, the firm-specific perceived elasticity, used in the mark-up equation. The latter can be derived from the industry elasticity, on the basis of the specific model of oligopoly that has been selected. This classical IO problem is reviewed, in the context of CGE models, by Francois (1998) and Willenbockel (2002). Perhaps the most popular option entails assuming a Cournot competition (a Nash equilibrium, in which production levels are taken as strategic variables) in a market with *n* symmetric firms. In this case, the firm-level elasticity (ϵ_{fi}) is simply given by:

$$\epsilon_{fi} = n\epsilon_i \tag{9}$$

Therefore, increasing the number of firm in a market produces a higher perceived elasticity, and a lower mark-up. To the limit, for *n* going to infinite, the profit mark-up vanishes and the market becomes perfectly competitive. More generally:

$$\epsilon_{fi} = \chi_{fi}\epsilon_i \qquad \chi_{fi} = \left(\frac{\partial q_i/q_i}{\partial q_{fi}/q_{fi}}\right)^{-1} \qquad q_i = \sum_f q_{fi} \tag{10}$$

where $q_{fi}$is the quantity produced by firm *f* in market *i*.

Notice that, if the parameter χ is assumed to be fixed (or, equivalently, the number of firms is fixed in a Cournot formulation), the industry and perceived elasticities vary proportionally. On the other hand, whereas the industry elasticity is computed from substitution elasticity parameters of the model, the perceived elasticity, because of its role in the mark-up equation 1, needs to consistent with observed (marginal) profits in the industry.

2.2 What is a market?

The term “market” usually refers to the place where goods or services are exchanged. So, for example, we say “the market for paddy rice in China” or, to a finer disaggregation scale, “the market for imported steel used by the car industry in Australia”. For reasons that will be explained in the following, CGE models with imperfect competition often adopt a different concept of market, based on the *origin* of trade flows, rather than on their final destination.

In standard CGE formulations, industries are modelled through a representative firm selling in all markets: domestic and foreign, intermediate and final consumption. In imperfect competition settings, the representative firm is replaced by a finite number of firms. Are these firms also selling in all markets? If yes, who are the competitors? How many there are? These questions are key to determine the actual degree of competitive pressure faced in each market.

The Armington assumption postulates that goods produced by representative firms, in different countries, are imperfect substitutes. If this hypothesis is retained under imperfect competition, goods produced by firms located in the same region turn out to be more easily substitutable, among themselves, than between goods produced in different regions. This amounts to adding a further layer in a nested structure of substitution possibilities.

Competition vis-à-vis foreign firms is already taken into account through the computation of the industry price elasticity (e.g, equations 7 and 9). Therefore, when the firm-level perceived elasticity is derived, only competition from domestic firms has to be accounted for. For example, if Cournot competition is assumed, the number of firms in equations like 9 refers to the number of firms active in the domestic origin of trade flows, *not* in the final destination market.

Often, domestic competition is modelled differently than international competition. Indeed, industry elasticities in equations like 6 are expressed as partial (price) derivatives of demand functions. In economic terms this amounts to assuming *price (Bertrand) competition in differentiated goods*.[4] If Cournot competition is assumed for domestic competition, this is like saying that each firm sets its profit-maximizing production level, while taking production levels of all domestic firms as given, but *prices* of all foreign firms as given.[5]

To eliminate this inconsistency, two options are available. The first solution is assuming that even firms within the same region compete à la Bertrand (with differentiated products). In practice, this adds one further layer in the demand structure; for example, a CES function among domestic firms.

The second option is dropping the Armington hypothesis altogether, like in Swaminathan and Hertel (1997). In this case, there should not be layers in the demand structure. All products of all firms would compete at the same level, e.g., within a single CES function, in all markets. Because of the very large number of firms active in any market, HA2 would then be a reasonable working hypothesis, greatly simplifying the estimation of the perceived price elasticity.[6]

[4]This is also sometimes called Hotelling competition.

[5]Clearly, any increase in production by one firm would imply a loss of demand for other firms. If supply is kept constant, prices for the other firms would fall. Therefore, assuming constant prices would entail a compensating decrease in production level of external firms.

[6]This would create other problems, though. For example, one should then explain why profit margins may differ among industries.

2.3 Economies of scale

There can be imperfect competition without economies of scale. However, imperfect competition is needed to accommodate economies of scale in a market equilibrium.

In a general equilibrium, cost functions are endogenously determined on the basis of the optimally selected mix of factors. In general, the cost structure depends on output levels, unless the production function is homothetic. In a homothetic function, demand for all inputs is proportional to output at constant (relative) factor prices, meaning that the average cost is fixed (that is, there are constant returns to scale). All popular functions used in CGE models are homothetic (Leontief, Cobb-Douglas, CES, or any nesting of homothetic functions).

Economies of scale exist (locally) if average production costs are (locally) decreasing in production levels. One simple way of introducing economies of scale is by assuming that a proportional increase in *all* factors entails a more than proportional increase in output *y*, which is equivalent to an increase in the multi-factor marginal productivity (*mfp*). Suppose that the *structure* of inputs is independent of the output scale; in this case, the cost function (*c(y)*) is proportional to factor inputs, and there exists a simple relationship between relative variations of total (multi-factor) productivity, average cost (*ac*) and marginal cost (*mc*):

$$\dot{mfp} = \frac{\partial y}{\partial c(y)} \frac{c(y)}{y} = \frac{ac(y)}{mc(y)} \tag{11}$$

Francois (1998) notice that the *ac/mc* ratio is constant if :

$$c(y) = ky^{\theta} \tag{12}$$

where *k* and θ are given parameters.

As a consequence, to get increasing returns in a model, it is sufficient to endogenously vary total productivity parameters in accordance with 11. Remember that decreasing average costs imply *ac>mc*, so that *ac/mc>1*, and multi-factor productivity becomes an increasing function of output volume.

An alternative way to introduce economies of scale is making an explicit distinction between variable and fixed costs. Variable costs depend on production levels. Therefore, they can be easily modelled through constant returns to scale, homothetic production functions, exactly like in the standard CGE closure with perfect competition. Fixed costs account for all costs that do not depend on production levels on the short run. As each individual firm incurs fixed costs when active on the market, industrial fixed costs depend on the number of firms, not on production volumes.

Gørtz and Hansen (1999) observe that fixed costs can be introduced by adding a fictious consumer, whose consumption levels do not depend on income, but on the number of firms. This technical solution has the merit of potentially solving one drawback associated with the total productivity approach. Indeed, the *mfp* solution implicitly postulates that variable and fixed costs have the same structure: this amounts to assuming that, in each year, a fraction of the *industrial product* is used to pay for fixed costs. If, instead, fixed costs are accounted for in a separate sector, different cost structures could be adopted.[7]

2.4 Calibration

Calibration is the standard procedure, by which structural parameters in a CGE model are estimated. It amounts to assuming that equilibrium conditions, as specified in the model, holds at a given time, for which economic data is available. Most of the data usually comes from a Social Accounting Matrix (SAM). The SAM can be used to estimate industrial production volumes, industrial demand for intermediate factors and value added components, prices and tax levels. However, it cannot provide the extra information required by an imperfect competition closure, like: relative amount of fixed costs, profit margins, number of firms, types of strategic interaction.

To see how the extra IC parameters can be estimated, let us consider three equations, defining the market equilibrium for an imperfectly competitive industry with symmetric firms:

$$p = ac(y) + \pi \tag{13}$$

$$Y(p, \ldots) = ny \tag{14}$$

$$p = \left(1 - \frac{1}{\epsilon(\chi)}\right)^{-1} mc(y) \tag{15}$$

Equation 13 is an accounting identity, stating that price equals the sum of average costs and unitary profits. Price are observed at calibration time.[8] All cost components are also observed, but profits are not. Profits are embedded in a residual component of the value added which, in standard CGE models, accounts for payments on capital services. Therefore, there are three options available for the determination of unitary profits:

- profits are estimated using additional information, breaking down the residual component of the industrial value added;
- profits are assumed to be initially zero.
- profits are assumed to be always zero, because of free entry in the market (monopolistic competition).

Equation 14 states that the sum of production levels for all the *n* symmetric firms must equal the total industrial output volume, which is itself a function of the industrial price and other variables.

[7]The sum of variable and fixed costs should be consistent with observed industrial costs in the base year, though.

Information on the structure of fixed costs is not readily available. Yet, independence of the cost structure to production levels is such a poor approximation, in many cases, that even educated guesses would provide a more realistic solution.

[8]Actually, units of measure are chosen for exchanged quantities, such that all prices are normalized to unity.

Is it possible to estimate the baseline number of firms? Clearly, real markets are not symmetric, so the question is selecting parameter values, such that the modelled industry satisfactorily "resembles" the real one. In some CGE models, information on market concentration is used to this purpose. A popular concentration index is the Herfindahl-Hirschman index (HHI): the sum of squared market shares of active firms.[9] The number of (symmetric) firms could then be estimated, such that the number of firms is consistent with the observed HHI index.[10] In general, nothing ensures that the estimated value for n is an integer number. This is not really a problem if n is not very small. However, there may be cases in which n turns out to be close to one. If $1<n<2$ we have a case of natural monopoly, meaning that economies of scale are very strong, and only one firm can survive in the market.[11]

Equation 15 is the usual mark-up equation, in which the elasticity value may depend on the number of firms. Some studies are available, providing estimates of industrial mark-ups (e.g., Oliveira-Martins and Scarpetta (1996), Abaysiri-Silva (1999), Maioli (2003)). If information on mark-ups and the number of firms has to be reconciled with estimated industrial elasticities, the only possibility is to add a degree of freedom, through the introduction of conjectural variation parameters (see equation 10). A well known problem of using arbitrary values for conjectural variations, however, is that the implied strategic behaviour may not be logically consistent (a competitive equilibrium may not be a Nash equilibrium).

To sum up, five additional pieces of information are involved in the calibration of a CGE model with imperfect competition, all referring to the base year:

1. initial unitary profits or industrial mark-ups
2. industry elasticities
3. number of firms or production level per firm
4. conjectural variations, which amounts to choosing a specific oligopoly model, or firm-specific perceived elasticities
5. a measure of economies of scale, expressed by the *ac/mc* ratio, or equivalent parameter

Since equations like13–15 have to be satisfied in the calibration equilibrium, not all the parameters above are needed. Several combinations are possible, in which some parameters are set ex-ante, while the remaining ones are obtained through calibration.[12]

[9]Notice that, as pointed out earlier in this paper, by "number of firms" we mean here the number of domestic firms in an industry.

[10]It turns out that this is just the inverse of the HHI, if the HHI is expressed as a number between zero and one.

[11]I am not aware of any CGE model that has satisfactorily addressed this problem. One solution could be fixing the number of firms, checking the profits generated by the model, and setting n at the highest integer number compatible with positive profits.

[12]Bchir *et al.* (2002) propose to fix profits to zero (and implicitly set conjectural variations) to choose the combination of marginal costs, number of firms, and industrial elasticities. For all these parameters ex-ante estimates are used, as well as a value for the variance of the estimate. For each sector, the values used in the model are chosen so as to minimize the squared distance from these estimates, weighted by the inverted variance of the logarithm of estimates, subject to the zero-profit constraint.

Since several options are available, it may not be surprising that there is no standard procedure for the calibration of a CGE model with imperfect competition.[13]

3 Introducing Imperfect Competition: Implications for Model Results

3.1 Shock Propagation

Results obtained by CGE models with imperfect competition are typically compared with results generated under a standard closure, with perfectly competitive markets. The aim is understanding whether or not adding imperfect competition makes a difference. The point we want to make here is that the answer relies on how some key parameters have been estimated.

Consider, for example, the effects on market prices of a variation of production costs. This variation may be due to changes in productivity, changes in taxes or subsidies or, as we shall consider later is this paper, to changes in the cost of production factors. In a perfect competition setting, any cost change simply translates into a price change. In imperfect competition, prices are determined by a mark-up over (marginal) costs. Therefore, *if the mark-up stays constant*, prices are proportional to costs. This means that, for example, a 1% increase in costs implies a 1% increase in price, both in perfect and imperfect competition.[14]

However, mark-ups do generally vary, according to the definition of perceived demand elasticity adopted in the model. As an illustration, consider the simple case of an industry (*i*) selling in just two markets (*1* and *2*), and competing (in each market) with only one other product (*j*). This case is taken here for simplicity, but it can easily be generalized to the case of multiple markets and multiple inputs. Equations 8 and 6 can be reformulated as:

$$\epsilon_i = z_i^1 \epsilon_i^1 + \left(1 - z_i^1\right) \epsilon_i^2 \tag{16}$$

$$\epsilon_i^r = \sigma^r - s_i^r \sigma^r \tag{17}$$

To start with, consider equation 16 and suppose that elasticities in the sub-markets are constant. This would be the case, for instance, if assumption HA2 has been adopted. Does the global elasticity vary after changes in the industrial price? Yes, because, even if sub-market elasticities are constant, market shares are not. In particular, we show in the Appendix that the following result holds:

$$\frac{\partial \epsilon_i}{\partial p_i} = -\frac{z_i^1 \left(1 - z_i^1\right)}{p_i} \left(\epsilon_i^1 - \epsilon_i^2\right)^2 \leq 0 \tag{18}$$

[13] Despite all this, methodological differences in the calibration of most existing models are not sufficiently highlighted and documented.

[14] Nonetheless, if the same SAM is used to calibrate a model for both perfect and imperfect competition, differences may arise, because of differences in baseline marginal costs. Marginal costs may be lower in imperfect competition if profits are assumed to be initially positive, so that the cost of capital is correspondingly reduced. When this happens, cost shocks may be relatively stronger in imperfect competition.

Therefore, any increase in price, for example due to higher production costs, is generally associated with a smaller elasticity (in absolute value), which means *a higher profit mark-up*. As a consequence, prices exhibit wider fluctuations in imperfect competition than in perfect competition: cost shocks have a more significant impact. Equation 18 also highlights under what conditions this effect is more significant, that is when (1) selling is not concentrated in a few markets, and when (2) sub-market elasticities are quite different.

Do sub-market elasticities stay constant? We show in the Appendix that:

$$\frac{\partial \epsilon_i^r}{\partial p_i} = -\frac{1}{p_i} s_i^r \left(1 - s_i^r\right) \sigma^r \left(1 - \sigma^r\right) = -\frac{1}{p_i} s_i^r \epsilon_i^r \left(1 - \sigma^r\right) \tag{19}$$

$$\sigma^r \geq 1 \Rightarrow \frac{\partial \epsilon_i^r}{\partial p_i} \geq 0 \qquad \sigma^r \leq 1 \Rightarrow \frac{\partial \epsilon_i^r}{\partial p_i} \leq 0 \tag{20}$$

That is, a sub-market demand elasticity may increase or decrease, depending on the value of the associated substitution elasticity. A sub-market elasticity stays approximately constant: (1) if the product is dominant in the sub-market or, vice versa, (2) if it is marginal; (3) if there is little substitution among goods; (4) if the substitution elasticity is close to one (the Cobb-Douglas case, implying constant cost shares).

Combining the results 18 and 19 we cannot establish, in general, if the mark-up will increase or decrease. However, since the sign of 18 is unambiguously negative, and the impact of 19 on the overall industrial elasticity is weighted by market shares, the first effect is likely to dominate in most circumstances. This means that cost shocks would have a wider impact in imperfect competition than in the standard competitive closure.[15]This effect is further amplified if production technology is characterized by economies of scale.

With free entry and exit in the market, the price is also determined by equality with average costs (13), and the number of firms is endogenous. In other words, mark-ups and perceived elasticities may change, even if industrial elasticities do not change. If, for example, a cost shock is interpreted in terms of higher marginal costs, this would generate higher prices, lower production volumes (at the industry and firm level), less firms in the market, a lower perceived elasticity and a higher profit mark-up. Therefore, this additional mechanism also amplifies the impact of cost shocks in imperfect competition.

3.2 Second-Best Economics

CGE models with imperfect competition may behave differently than standard CGE models. This is true not only in quantitative terms, as we noticed above, but also from a qualitative perspective, and especially in terms of welfare. In essence, the differences rely on a distinction between first and second-best optima.

General equilibrium theory tells us that an unrestricted perfectly competitive equilibrium is a Pareto optimum. This means that global welfare cannot be improved further. A calibrated equilibrium in a standard CGE is not an optimum, however, because of the existence of distortionary taxes and subsidies. Any policy reducing the amount

[15]Notice that, in a partial equilibrium model with linear demand curves, the opposite result holds.

of initial distortion is globally beneficial, as it can be interpreted as a step towards the right direction. For example, trade liberalization is good (globally). Substitution of a tax with another one, having a larger base, is also good.

Things are not so straightforward under imperfect competition. This is because of the presence of market power in some industries, creating an additional distortion, in terms of excessively low production volumes. In a second-best world, when a distortion is added on top of another distortion, the situation may not necessarily worsen. In the same vein, removing a distortion may not be always beneficial. This is because distortions can (partly) compensate each other.

Economies of scale add further complications. Even if there is no market power (e.g., in the case of natural or regulated monopoly), economies of scale are associated with excessively low production and consumption levels. Non-convexities and multiple equilibria can be easily found. For example, production of a homogeneous good can be concentrated in one region, or another. It could be possible, therefore, that introducing shocks in economies, characterized by increasing returns to scale, may bring about non-marginal changes in the equilibrium state.

4 An Illustrative Simulation Exercise

To illustrate the main points discussed in this paper, we present a simulation exercise based on the GTAP database and model, suitably modified to embody imperfect competition features in some industries.[16]

The GTAP database is a SAM matrix of the world economy which, in its latest version (6-2001 data), is disaggregated in 86 regions/countries, 56 industries and 5 primary resources. For this simulation, we choose to aggregate the data to three regions, three industries and four primary factors. Regions include: EU at 25 countries (including new accession countries), NAFTA (USA, Canada, Mexico), and Rest of the World (ROW). Sectors are: Agriculture (Agric - including fisheries and forestry), Manufacturing (Mnfcs - including food processing) and Services (Svces).

The GTAP model is a conventional, comparative static CGE model, that can be calibrated with the GTAP database, at any level of aggregation. The structure of the model is fully described in Hertel (1996).[17] In the model, goods and services are produced by competitive regional industries and sold to domestic and foreign industries and consumers. A representative agent in each region receives income from the value of the owned primary resources,[18] and allocate the expenditure between savings, private and public consumption. Utility maximization and cost minimization are the behavioural rules for the price-taking firms and consumers.

[16] The model code, written in the TABLO language for the GEMPACK software, is a available at: http://venus.unive.it/roson/Soft.htm .

[17] Any release of the GTAP database is accompanied by an updated version of the GTAP model. Therefore, the structure of the current model is slightly different from the one described in the reference, but changes are only marginal. Several variants of the basic model exist. For example, dynamic/multiperiodal, or having a different formulation of energy consumption and emissions. More information on the model, data sources and applications can be found in the GTAP website: www.gtap.org .

[18] Labour and capital stock are perfectly mobile domestically, whereas land and natural resources are imperfectly mobile. All primary factors are internationally immobile.

Demand for any produced good comes from domestic and foreign markets. The so-called Armington assumption is adopted, meaning that goods within the same industry, but produced in different regions, are considered to be imperfect substitutes. For all intermediate and final demand components, substitution occurs within a double-nested structure. At a lower level, goods produced in different foreign countries are combined (through cost-minimization in a CES function) in an import composite good. The elasticity of substitution used in this process is quite high: 7.524. At a higher level, the import composite is combined with the domestic product, using an elasticity of substitution of 3.155.

The model can be calibrated with the GTAP database, so that general equilibrium is assumed to hold for the base year (in this case, 2001). A general equilibrium is a state in which supply matches demand in all markets: goods, services and primary factors. Simulations are typically carried out by shocking one exogenous parameter,[19] and generating a new, counterfactual equilibrium. Comparison between the two equilibria provides useful information about structural changes, variations in trade flows, relative competitiveness and welfare.

We have modified the basic GTAP model, to allow for the possible existence of market power in some industries. In this case, we continue to assume constant returns to scale, and we take as a given the number of firms in imperfectly competitive industries.[20] In these industries, profits are accounted for through the inclusion of a fictious endowment commodity, whose supply is endogenously adjusted by the model, so as to satisfy the mark-up equation 1, where marginal costs are computed as the cost of all factors (primary and intermediate) used in the production process, except the fictious profit resource.

The model is calibrated by assuming that both baseline profits and capital debt service are included in the SAM capital income flow. Therefore, for all imperfectly competitive industries of all regions, the calibration database needs to be integrated by a set of coefficients that tells the model how the initial capital endowment has to be split in the two components: profits and actual capital. In this simulation, we assume that imperfect competition only occurs in manufacturing industries and, to this purpose, we use parameters consistent with estimates of mark-ups obtained by Oliveira-Martins and Scarpetta (1996).[21]

We use this modified GTAP model to run a typical simulation exercise of trade liberalization. More precisely, we simulate the unilateral removal of all import tariffs and export subsidies for agricultural goods in the EU-25. Since agriculture is a much protected industry in Europe, this policy implies a significant drop of agricultural prices in Europe and an increase in world prices. Trade flows among the three regions vary as shown in Table 1.

[19]The partition between endogenous and exogenous variables in the model is not fixed, and can be easily changed.

[20]This number is not computed. This is because the model equations are formulated in terms of percentage change, so it is not necessary to know the value of any parameter that is kept constant in the simulations.

[21]A simple, unweighted average of mark-ups for all manufacturing industries gives a share of profits in total output value of about 13%, for all regions. Remarkably, this is only slightly below the share of total capital income of our baseline SAM (EU 13.8%, ROW 14.77%, NAFTA 15.55%). Other works in the empirical literature have found higher mark-ups, whose values would be inconsistent with our database.

Table 1: Changes (%) in trade flows of agricultural goods

From\to	***NAFTA***	***EU***	***ROW***
NAFTA	0.34	7.15	1.51
EU	-1.99	-7.86	-9.35
ROW	-0.69	20.2	0.44

Table 2: Changes (%) in trade flows of manufactured goods

From\to	***NAFTA***	***EU***	***ROW***
NAFTA	-0.06	-0.42	-0.12
EU	0.67	0.31	0.61
ROW	-0.17	-0.53	-0.23

The manufacturing sector (the only one where firms have some market power) is not directly affected by the trade liberalization policy. However, there are impacts on this industry as well, both because some intermediate inputs are purchased from the agriculture sector, and because there are changes in the composition of the intermediate and final demand in all industries and regions. Table 2 shows how changes in trade flows for manufactured goods have been estimated by the model.

Notice how the European manufacturing industry improves its relative competitiveness, increasing sales in both foreign and domestic markets. However, because demand elasticity is higher in foreign markets, foreign market shares increase and the overall demand elasticity increases as well. As a consequence, profit margins shrink. Table 3 compares the results obtained for supply prices of all industries in two model runs, one with the standard GTAP model and the other one with the IC variant.

Under imperfect competition, price variations are wider. For example, prices of European manufactured goods diminish, not only because of cheaper agricultural inputs, but because of lower profit margins. More generally, imperfect competition acts here as a booster of policy impacts. Other results (in terms of production volumes, consumption levels, etc.) have a similar interpretation.

The most striking differences in the output of the two model simulations can be found in the estimation of the equivalent variation (EV). The EV is the hypothetical change in income which would have produced the same effect on the welfare of representative consumers in the three regions, at constant (baseline) prices. Table 4 presents the results for this money-metric measure of changes in utility levels.[22]

Two points are worth to be noticed here. First, trade liberalization, even a unilateral one, brings about aggregate welfare gains. This is a standard result in models with a Hecksher-Ohlin-Samuelson structure, like this one. However, when imperfect competition is taken into account, welfare gains are larger. This is because there is a reduction

[22] In millions of 2001 US$.

Table 3: Changes (%) in supply prices, in two model versions

PERFECT COMPETITION IN ALL INDUSTRIES

Ps (PC)	***NAFTA***	***EU***	***ROW***
Agric	0.25	-1.19	0.51
Mnfcs	0.01	-0.06	0.02
Svces	0	0.01	-0.02

IMPERFECT COMPETITION IN MANUFACTURING

Ps (IC)	***NAFTA***	***EU***	***ROW***
Agric	0.26	-1.21	0.5
Mnfcs	0.02	-0.08	0.03
Svces	0.01	-0.04	0

Table 4: Estimates of equivalent variation (EV) in two model versions

EV	*PC*	*IC*
NAFTA	54.78	836.48
EU	721.72	-3.99
ROW	-419.63	-307.69
Total	356.87	524.8

of market power in the European manufacturing industry, curbing one type of market distortion, in addition to the one associated with trade barriers.[23]

Second, the *distribution* of gains is strikingly different between the two scenarios. Europe is the region benefitting most under perfect competition, but it is almost unaffected, in terms of welfare, if there is market power in manufacturing. On the contrary, North American countries grab most of the gains in the latter case. The reason behind the differences has to do with changes in the terms of trade. In essence, market power acts as a sort of export tax in foreign markets. An export tax is beneficial to the home country (but not globally), to the extent that part of the tax is paid by foreigners.

5 Concluding Remarks

Introducing imperfect competition in a Computable General Equilibrium model entails inserting and adapting concepts originally conceived for partial equilibrium models of Industrial Organization. Not surprisingly, the whole undertaking is not straightforward, as it involves a series of conceptual issues, and it is not a daunting, technical task, whose description has to be relegated in a short appendix, at the end of the paper.

A number of alternative options in model design have been examined in this paper, and some implications for the qualitative behaviour of the model in simulation experiments have also been briefly discussed, especially in terms of comparison with the standard CGE closure of perfect competition. Some points have been illustrated by means of a numerical exercise, where a unilateral trade liberalization policy in agriculture (with and without market power in manufacturing) has been simulated.

Acknowledgements

This study is part of a project on economic modeling of climate change impacts, involving the Abdus Salam International Centre for Theoretical Physics (Trieste, Italy), the Fondazione Eni Enrico Mattei (Italy) and Hamburg University. Financial support from MURST (PRIN 2003) and the University of Genoa is gratefully acknowledged.

References

Kaludura Abaysiri-Silva (1999), *Market Power in Australian Manufacturing Industry: a Confirmation of Hall's Hypothesis*, CEPS - Impact Project General Paper n. G-132, Monash University, Melbourne, Australia.

Mohamed Hedi Bchir, Yvan Decreux, Jean-Louis Guérin and Jean Sébastien (2002), *MIRAGE, a Computable General Equilibrium Model for Trade Policy Analysis*, CEPII working paper n.2002-17.

[23]Therefore, in this specific exercise, pre-existing market distortions reinforce the primary effect of the implemented policy. In other cases, however, initial distortions could counteract, nullify, and even reverse the effect of other policies.

Joseph F. Francois (1998), *Scale Economies and Imperfect Competition in the GTAP Model*, GTAP Technical Paper No. 14, Center for Global Trade Analysis, Purdue University.

Masahisa Fujita, Paul Krugman and Anthony J.Venables (1999), *The Spatial Economy - Cities, Regions, and International Trade*, MIT Press.

Mette Gørtz and Jan V. Hansen (1999), *Regulation of Danish Energy Markets with Imperfect Competition*, Working Paper 1999:2, Danish Economic Council.

Richard Harris (1984), "Applied General Equilibrium Analysis of Small Open Economies with Scale Economies amd Imperfect Competition", *American Economic Review*, vol. 74(5), pp. 1016-1032.

Glenn Harrison, Thomas Rutherford and David Tarr (1997), "Quantifying the Uruguay Round", *Economic Journal*, vol. 107, pp.1405-1430.

Hertel, T.W. (1996), *Global Trade Analysis: Modeling and Applications*, Cambridge University Press.

Anders N. Hoffman (1999), *Imperfect Competition in General Equilibrium Models - A Primer*, Mimeo, MobiDK project, University of Copenhagen and Ministry of Business and Industry, Denmark.

Sara Maioli (2003), *A Joint Estimation of Markups and Returns to Scale in 22 French Industries: a Structural Approach*. Mimeo, GEP University of Nottingham, U.K.

Oliveira-Martins, J. and Scarpetta, S. (1996), *Mark-up ratios in manufacturing industries: Estimates for 14 OECD countries*, OECD Economics Department Working Papers No. 162.

Padma Swaminathan and Thomas W. Hertel (1997), *Introducing Monopolistic Competition into the GTAP Model*. GTAP Technical Paper No. 6, Center for Global Trade Analysis, Purdue University.

Dirk Willenbockel (2002), *Sensitivity of CGE Trade Policy Analysis under Imperfect Competition to the Specification of Firm Conduct*, Mimeo, Middlesex University London.

Appendix

Derivation of equation 18

$$\frac{\partial \epsilon_i}{\partial p_i} = \left(\epsilon_i^1 - \epsilon_i^2\right) \frac{\partial z_i^1}{\partial p_i}$$

$$\frac{\partial z_i^1}{\partial p_i} = \frac{\partial q_i^1}{\partial p_i} \frac{1}{q_i^1 + q_i^2} - \frac{q_i^1}{\left(q_i^1 + q_i^2\right)^2} \frac{\partial \left(q_i^1 + q_i^2\right)}{\partial p_i} =$$

$$= \frac{1}{q_i^1 + q_i^2} \left(-\frac{q_i^1}{p_i} \epsilon_i^1 + z_i^1 \frac{q_i^1 + q_i^2}{p_i} \epsilon_i \right) =$$

$$= -\frac{z_i^1 \left(1 - z_i^1\right)}{p_i} \left(\epsilon_i^1 - \epsilon_i^2\right) \quad \blacksquare$$

Derivation of equation 19

$$\frac{\partial \epsilon_i^r}{\partial p_i} = -\frac{\partial s_i^r}{\partial p_i} \sigma^r$$

$$s_i^r = \frac{p_i q_i^r}{p_i q_i^r + p_j q_j^r} = \frac{\tilde{p}\tilde{q}}{\tilde{p}\tilde{q} + 1} \qquad \tilde{p} = \frac{p_i}{p_j} \; \tilde{q} = \frac{q_i^r}{q_j^r}$$

$$\frac{\partial s_i^r}{\partial p_i} = \frac{\partial s_i^r}{\partial \tilde{p}} \frac{1}{p_j}$$

$$\frac{\partial s_i^r}{\partial \tilde{p}} = \frac{1}{\left(\tilde{p}\tilde{q} + 1\right)^2} \frac{\partial \left(\tilde{p}\tilde{q}\right)}{\partial \tilde{p}}$$

$$\frac{\partial \left(\tilde{p}\tilde{q}\right)}{\partial \tilde{p}} = \tilde{q} \left(1 - \sigma^r\right)$$

$$\frac{1}{p_j} \frac{\tilde{q}}{\left(\tilde{p}\tilde{q} + 1\right)^2} = \frac{1}{p_i} \frac{p_i q_i^r}{p_j q_j^r} \left(\frac{p_j q_j^r}{p_i q_i^r + p_j q_j^r} \right)^2 = \frac{1}{p_i} s_i^r \left(1 - s_i^r\right) \quad \blacksquare$$

NOTE DI LAVORO DELLA FONDAZIONE ENI ENRICO MATTEI

Fondazione Eni Enrico Mattei Working Paper Series

Our Note di Lavoro are available on the Internet at the following addresses:
http://www.feem.it/Feem/Pub/Publications/WPapers/default.html
http://www.ssrn.com/link/feem.html
http://www.repec.org
http://agecon.lib.umn.edu

NOTE DI LAVORO PUBLISHED IN 2006

2006 SERIES

CCMP	*Climate Change Modelling and Policy* (Editor: Marzio Galeotti)
SIEV	*Sustainability Indicators and Environmental Valuation* (Editor: Anna Alberini)
NRM	*Natural Resources Management* (Editor: Carlo Giupponi)
KTHC	*Knowledge, Technology, Human Capital* (Editor: Gianmarco Ottaviano)
IEM	*International Energy Markets* (Editor: Anil Markandya)
CSRM	*Corporate Social Responsibility and Sustainable Management* (Editor: Sabina Ratti)
PRCG	*Privatisation Regulation Corporate Governance* (Editor: Bernardo Bortolotti)
ETA	*Economic Theory and Applications* (Editor: Carlo Carraro)
CTN	*Coalition Theory Network*