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A Survey of the Empirical Literature

by

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Abstract

If firms were animals rather than economic entities, a behavioral scientist trying to describe their traits would observe that firms tend to be found in herds and usually migrate towards the biggest watering holes. This paper surveys the literature on the questions why firms grow stronger with size, why they are found in herds, and what the effects are of meeting other herds around the watering holes. In economist-speak, I review the empirical literature on internal and external economies of scale. Internal scale economies arise on the level of a single firm. External scale economies arise on the level of an industry or a region. For each type of scale economies, I consider static and dynamic effects.

JEL-Classification: D24, R30

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Contents

1. Introduction*

Economies of scale (EOS) have been at the heart of developments in economic theory in the past two decades. Breakthroughs in the field of industrial organization now allow for the modeling of more complex market structures. This has stimulated important developments in the fields of international trade, economic growth, location and real business cycle theory. Two types of scale economies can be considered. EOS that are internal to the firm are an important ingredient for modeling monopolistic competition. With an increasing demand for models with a more rigorous microeconomic foundation and an increasing interest in different market structures, monopolistic competition has become a standard ingredient in several fields of economic theory. EOS that are external to the firm are important for the explanation of cumulative phenomena, multiple equilibria and path dependencies.

Despite their important impact on economic theory, empirical evidence on EOS remains elusive and stays behind the theoretical contributions to this topic. This paper intends to survey the empirical literature on EOS and to assess their empirical relevance for real world economic phenomena. Section 2 classifies different types of EOS, discusses their theoretical implications, and refers to some of their most important theoretical contributions. Section 3 surveys empirical papers on EOS that are internal to the firm, and section 4 surveys empirical papers on EOS that are external to

* For helpful comments on a previous version, I would like to thank Andreas Gröhn, Erich Gundlach, Matthias Lücke and Dieter Urban.

the firm. Both sections distinguish between static and dynamic effects. Section 5 summarizes and concludes.

2. A Framework for the Analysis

2.1 Classification of Economies of Scale

The terms internal and external economies of scale are used differently by different authors. The crucial difference is the level of aggregation at which the dividing line is drawn. Some authors refer to the industry as the main object of study. Then internal EOS arise on the industry level, whereas external EOS arise on the regional level. In this survey, I distinguish EOS on the firm level, the industry level, and the regional level. I use the term internal EOS with reference to the single plant or firm only. This has the advantage that internal refers to those EOS that can be influenced by the action of a single economic agent. External EOS then refers to those EOS that cannot be influenced by a single economic agent. They arise on the industry level or regional level, which are aggregates of economic agents that usually do not form a unit of economic decision making.

As a consequence, I distinguish internal and external, and static and dynamic EOS. Internal EOS (InEOS) arise on the level of the single firm. External EOS (ExEOS) arise on the level of the industry or the region. Static EOS raise productivity levels. Dynamic EOS raise productivity growth rates.

Static InEOS reduce the unit costs of the plant or firm with an increase of its own current output at that point in time. InEOS prevail if the elasticity of costs with respect to firm output is less than one. This means that unit costs fall with an increase in output at any point in time, because of decreasing marginal costs or the existence of fixed costs in production. InEOS can have several sources. An important source are indivisibilities or the spreading of fixed costs over a larger scale of output. Additional sources may be laws of nature or technical-physical relationships (Berndt 1991, p. 61), economies of increased dimensions and economies of specialization. With a higher output, workers can specialize more narrowly on a special task that they may better perform than if they devoted only a fraction of their work time to that task.[1]

Dynamic InEOS reduce the unit costs of the firm with an increase in its cumulative output. They are also called learning effects. An increase in firm output may lead to higher productivity through learning such that unit costs decrease over production time. Additionally, spreading of certain costs like costs for patents, product development and costs for capital equipment and plant construction decrease unit costs over time. They are independent of the scale of production, but necessary for any productive

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1 Other sources of InEOS are superior techniques or organizations of production and economies of massed resources (Robinson, 1958). Economies of massed resources reflect the argument that small firms have to stock resources at a larger percentage of their production than large firms. This occurs because replacement parts per machine and other reserves can be reduced due to a lower variance of the breakdown rate for a higher number of machines used. See Pratten (1971) and Scherer (1975, chap. 4) for an overview and further discussion of the sources of InEOS, its limits and offsetting forces. Scherer (1975) provides numerous references on early theoretical and empirical work. See also Scherer and Ross (1990), who surveys economies of scale and Jorgenson (1986), who discusses econometric issues concerning the different modelling of producer behaviour under constant and increasing returns to scale.

activity. Further sources are improvements in organizational structures, capacity of workers to work more productively and technological improvements. These improvements may be different in different stages of production. Firms in new industries are more likely to exhibit large learning effects than in mature industries.

To sum-up, static InEOS lead to a downward movement along the average costs curve due to an increase in current output at a given point in time. Learning effects lead to a downward shift of the average costs curve due to cumulative output.

In the case of external EOS (ExEOS), also called positive external effects, externalities or agglomeration economies, firms benefit from being close to other firms. Then agglomeration of economic activities is advantageous because of backward and forward linkages in the production of goods, labor market pooling, sharing of common assets like infrastructure, and knowledge or technological spillovers. Static ExEOS result in a higher productivity level, whereas dynamic ExEOS result in a higher productivity growth rate. Making a difference between static and dynamic ExEOS is important even if both lead to agglomeration economics, because the origin of these externalities is very different.

Static ExEOS prevail if the elasticity of unit costs of a firm with respect to industry or regional output is less than one. They reduce unit costs of a firm through an increase in the output of other firms. The increase in output may take place on the level of the industry or the region, depending on the origin of the external effects. If the origin of the externalities lies within the firm's own industry they are called localization

externalities (LocEOS). Then unit costs decrease with the output of all firms of the industry. Localization advantages are for instance labor market pooling, asset sharing, and the availability of more specialized intermediate input suppliers. If the origin of the externalities lies within the region or the city where the firm is located, they are called urbanization externalities (UrbEOS). Then unit costs decrease with the output of all firms in the region. An urbanization advantage is for instance the proximity to consumers, which reduces transport and marketing costs.[2]

Dynamic ExEOS speed up growth rates of an industry. They arise as geographic concentration of firms helps knowledge or technologies to spill over from firm to firm. A distinction has been made concerning the nature of the externalities. Marshall (1920), Arrow (1962) and Romer (1986) assume that most learning and knowledge spillovers take place within individual industries, while Jacobs (1969, 1984) suggests that the most significant spillovers come from outside the own industry, even if they are more rare. Therefore, dynamic ExEOS are called Marshall-Arrow-Romer externalities (MAREOS) if they are of an intra-industry nature. They are called Jacobs externalities (JaEOS) if they are of an inter-industry nature. That is, dynamic

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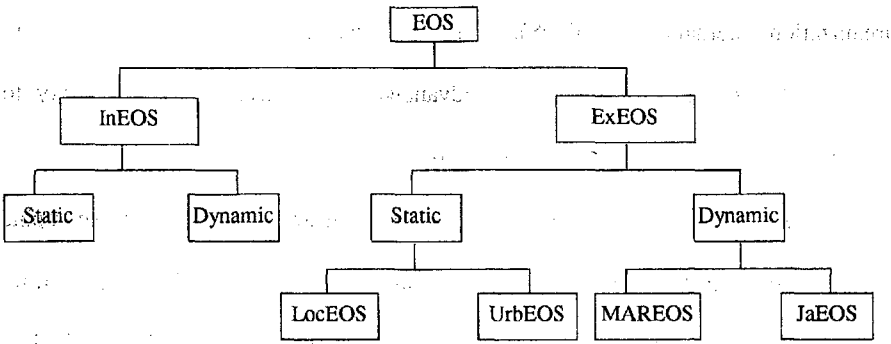
2 The distinction between localization and urbanization economies goes back to Isard (1956, pp. 182-188).

MAREOS correspond to the static LocEOS and dynamic JaEOS correspond to static UrbEOS.[3] Figure 1 summarizes these definitions.

Figure 1 — Classification of Economies of Scale



In this survey, two concepts of increasing returns are not considered. First, I leave out the distinction between EOS on the plant level and on the firm level. The reduction of unit costs due to the joint production of a range of goods and services at the firm level is called economies of *scope*. Scherer et al. (1975) argue that economies of scope are fueled by the following sources: Risk spreading and finance of capital raising, advantages of scale promotion, research and development spillovers, multiplant production and physical distribution, more economical management services, a

3 The literature often does not clearly distinguish between static and dynamic ExEOS. Therefore, one often finds that localization and MAREOS are used synonymously, because both are intra-industry externalities. Similarly, often urbanization and JaEOS are used synonymously, because both are inter-industry externalities.

common pool of financial planners, accountants, market researchers and lawyers, and economies of specialization in several functions on the managerial level. Empirically, economies of *scale* and economies of *scope* are difficult to disentangle, because most firms have a number of plants or produce a range of related products and services. Then costs are often difficult to relate to a special product. By using a broader definition of a product group in the remainder of the paper, I assume that each firm produces one product only, which allows me to focus on InEOS rather than economies of scope and to set equal plant and firm level EOS.

Second, I also leave out EOS due to network externalities as modeled by Farell and Saloner (1985) and Katz and Shapiro (1985). With network externalities, the utility derived from the consumption of a good rises with the number of consumers of the same good. Network externalities are EOS on the demand side, while this survey focuses on the supply side. The telephone network is an example for such demand side effects, since the value of a telephone for one person rises with the number of people she can talk to. Since there is often only the choice between very few alternative standards or networks, empirical evidence of demand side externalities mostly takes the form of anecdotes. Common examples are those of Betamax versus VHS videosystems, the QWERTY versus the Dvorak keyboard, or Netscape versus other

Internet browsers (David (1985), Arthur (1994, 1996)).[4] For the lack of rigor,[5] the empirical evidence on network externalities will not be discussed further in this survey.

2.2 *Theoretical Implications of Economies of Scale*

As early as 1928, Young (p. 528) referred to the "simpler and more inclusive view, such as some of the *older economists* took when they contrasted the increasing returns which they thought were characteristic of manufacturing industry taken as a whole with the diminishing returns which they thought were dominant in agriculture." (Emphasis added). And Bhagwati (1993, p. 17) points out that "The trade theorists who have used imperfectly competitive models recently and who then proceed to claim to be pioneers in thinking of possible theoretical arguments for departures of free trade, appear to us like men who, on visiting a prostitute, boast of having robbed her of her virtue". Indeed one finds increasing returns in as early work like Smith (1776) and

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4 Counterevidence usually does not challenge the existence of network externalities, but it questions the conclusion that network externalities necessarily result in inferior market solutions. See, for instance, Liebowitz and Margolis (1990, 1994), who question the inferiority of the QWERTY keyboard to the Dvorak keyboard and the equality of the VHS system relative to the Betamax system. For the lack of rigour of the evidence and counterevidence it is difficult to say whether QWERTY or Dvorak keyboards are better. However, the superiority of the QWERTY keyboard to other keyboards is questionable for another reason. There are more than the two possibilities to arrange the keys on a keyboard. Adopting a different combination imposes virtually no costs to the producer. With 48 keys on my keyboard, each at least double taken, there are apart from QWERTY and Dvorak at least 96! - 2 combinations to sort the keys - a number too large to calculate it with my pocket calculator. Only if no other combinations allows faster typing than QWERTY, something which is hardly imaginable, then the market solution is indeed the superior one.

5 Notable exceptions are Gandal (1994), Gröhn (1996a) and Nelson et al. (1994). See also the survey in Gröhn (1996b). Some of these authors use hedonic price approaches to estimate the value of the installed base of a good as a proxy for the size of network externalities.

Ohlin (1933). Adam Smith suggested that increasing returns may lead to differences in national per capita income levels and Ohlin stressed their role for explaining international trade flows.[6]

However, despite their early recognition, EOS have not played a major role in economic theory until the 1970s. Conventional theory instead built on the assumption of constant returns. This has only partly been due to the difficulties with which EOS could be modeled. It was also due to the unconventional properties of EOS. These properties can be summarized under four points.

Path dependence: In regional economics, path dependencies mean that any random disturbance from an equal dispersion of industries would be amplified by the existence of ExEOS. EOS have a self reinforcing mechanism. Myrdal (1957) called this circular causation, Arthur (1987, 1990a) uses the term positive feedbacks, and Hirschman (1958) refers to forward and backward linkages. All these expressions mean that if one region or technology starts with an initial cost advantage, EOS put it on a path that deepens this advantage. Such a path leads away from the initial configuration. Thus, EOS are non-ergodic, which means that "small events are not averaged away or forgotten by the dynamics - they may decide the outcome" (Arthur, 1989, p. 117). The

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6 Furthermore, Siebert (1969, p. 534) suggested that learn and search processes may explain EOS and that these can lead to path dependencies. In regional economics, Christaller (1933) and Lösch (1940) argued that EOS can cause a distribution of manufacturing producers in the form of a lattice of urban sites across an agricultural plain. Economies of agglomeration have further been investigated by Weber (1909) and Hoover (1948), and it is still common to talk about ExEOS as „Marshallian externalities" due to the discussion of the topic in Marshall (1920). In addition, Marshall was the first to distinguish between internal and external EOS.

same concept applies to firms that compete for market shares and to countries that may realize dynamic comparative advantages.

Multiple equilibria: EOS can lead to multiple equilibria. In regional economics, this means that out of several equally endowed regions that compete as locations of industrial production, each could end up with the bulk of industries if firms were free to set up production in any region. If EOS are unbound, circular causation would lead to the dominance of one region and, consequently, to a new equilibrium in which this randomly enlarged region specializes in the production of industrial goods. But any other region could have been in its place as well. This means that EOS also lead to *unpredictable* and *indeterminate* solutions in the case of multiple equilibria. Furthermore, it implies non-linearities that may introduce *analytical difficulties* in the calculation of explicit solutions.

Lock-in effects: EOS can lead to lock-in effects. The self-reinforcing mechanism that favors a technology, a region, or a firm that experienced an initial head-start can exclude other technologies, regions or firms from successful competition. An equilibrium that is once reached will be locked in and cannot be reversed by the market process in the presence of EOS. This means that EOS lead to *inflexible* solutions out of which exit is difficult.

Inefficiencies: If multiple equilibria are possible, then it is equally well possible that an inferior equilibrium becomes dominant just because of an initial head start. David (1985) argues that the QWERTY ordering of letters on a typewriter keyboard is an

inefficient technological standard that has been locked in by an early accident. Cowan (1990) points out that dynamic EOS through learning and construction experience have locked in the nuclear industry into the use of light water reactors despite gas-cooled reactors might have been superior. Therefore, EOS may lead to monopolistic and inefficient solutions. They can create barriers to entry, thereby, protecting early entrants from effective market competition. Together with the failure to internalize positive external effects of production and too low output levels, this is why EOS may lead to *market failures*. Under certain conditions, these in turn may justify government intervention.

For long, the above properties of EOS did not appear very appealing. About multiple equilibria, for instance, Schumpeter wrote[7]: "Multiple equilibria are not necessarily useless, but from the standpoint of any exact science the existence of a uniquely determined equilibrium is, of course, of the utmost importance, even if proof has to be purchased at the price of very restrictive assumptions; without any possibility of proving the existence of [a] uniquely determined equilibrium ... a field of phenomena is really a chaos that is not under analytical control." In 1939, Hicks even warned that admitting increasing returns would lead to "the wreckage of the greater part of economic theory".[8] This did not happen mainly due to improvements in the theory of industrial organization. Notably Spence (1976) and Dixit and Stiglitz (1977)

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7 Quoted from Arthur (1990, p. 95).

8 Quoted from Arthur (1996, p. 102).

improved the modeling of InEOS and Chamberlinian monopolistic competition.[9] Progress in computer technologies has made it easier to handle even very complex models and to work with models exhibiting analytically awkward properties like path dependence and multiple equilibria. Consequently, numeric solutions and simulation methods become increasingly accepted as methodological approaches in economics.

2.3 The Expanding Domain of Economies of Scale in Economic Theory

Departing from industrial organization, EOS have conquered a number of subfields in economic theory in recent years, beginning with international trade theory. In international trade theory, the introduction of InEOS in combination with preferences for variety made possible an explanation of the large portion of intra-industry trade in total trade, which could not well be explained by traditional trade theory relying on constant returns.[10]

In location theory, ExEOS have long served to explain why firms may want to locate near other firms. The explanation of agglomeration economies by ExEOS has been called the Folk-Theorem of spatial economics (Scotchmer and Thisse, 1992). The formation of agglomerations is explained by a higher productivity level or higher

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9 See Matsuyama (1995) for a survey, where monopolistic competition models are applied to explain cumulative phenomena in macroeconomics. He also refers to several other surveys that discuss monopolistic competition from a purely theoretical or industrial organization point of view.

10 See Krugman (1979, 1981), Lancaster (1980), Ethier (1982), Dixit and Norman (1980) and Siebert (1994).

profits that arise by the existence of static ExEOS. In modern location theory, InEOS have helped to build formal microeconomic foundations for the models. For models with internal as well as external EOS see Rivera-Batiz (1988), Abdel-Rahman (1988), Krugman (1991) and Krugman and Venables (1995).[11]

In economic growth theory, the introduction of ExEOS made possible an endogenous explanation of economic growth. In these models, learning by doing, investment in R&D, or the development of specialized inputs to production lead to dynamic economies of scale that enhance growth.[12] In development economics ExEOS contributed to the explanation of poverty traps, big-push industrialization, and unequal economic development.[13]

Also modern real business cycle models often rely on either monopolistic competition, EOS, or both. See Devereux et al. (1996), Evans et al. (1996), Gali (1994), Hornstein (1993), Kiyotaki (1988), and Rotemberg and Woodfort (1993) for an overview.

Moreover, EOS have stimulated discussions about optimal economic policies. If firms operate on the decreasing part of the average costs curve, there are potential

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11 Abdel-Rahman and Fujita (1990) show why both internal as well as external EOS are important for the explanation of agglomeration economies. They show that the spatial structure of models with and without a micro foundation based on a monopolistic competitive structure are the same. However, the policy conclusions differ substantially. See also the recent surveys on agglomeration economies by Fujita and Thisse (1996) and Schmutzler (1995). For empirical examples see Porter (1990).

12 See Romer (1986, 1990), Lucas (1988), Grossman and Helpman (1991) and Siebert (1991).

13 See Murphy et al. (1989), and the special issue of the Journal of Development Economics (Vol. 49, No. 1, 1996) on increasing returns, monopolistic competition and economic development.

benefits of an increase in scale. Government interventions might be justified, because EOS can lead to market failures. Then the specific nature of EOS plays a crucial role. If they are external to the industry, selective industrial targeting will not be successful. Strategic trade policy, industrial or technology policy and regional policy are further fields where the discussion of economic policies is based on the prevalence of EOS.[14]

Since EOS have had a considerable impact on economic theory and economic policy discussion, it is important to understand the extent to which EOS matter in practice. Unfortunately, there is no general consensus about their existence, not to speak of their quantitative importance. This is why I review the empirical findings on EOS on different levels of aggregation in chapter 3 and 4. These chapters are structured according to the classification of EOS as outlined in section 2.1. The next subsection lays out some general principles of modeling EOS in production and cost functions in order to explain how to test for the existence of EOS on the different levels of aggregation.

2.4 Modeling Economies of Scale

In the following, I lay out the modeling of EOS in the production function and cost function framework, and show how to arrive at an equation that can be estimated for

[14] See Brander and Spencer (1983), Dixit and Kyle (1985), Eaton and Grossman (1986), Horstmann and Markusen (1986) and Siebert (1988) for strategic trade policy and Stolpe (1995) and Siebert (1992) for technology policy.

the different types of EOS.[15] For simplicity, I use the following Cobb-Douglas production function:

$$(2.1) \quad Y = A \cdot x_1^{\alpha_1} x_2^{\alpha_2},$$

where Y denotes firm output, A denotes a general productivity parameter, and x_1 and x_2 are inputs with α_1 and α_2 as their elasticities. Returns to scale can be expressed as $r = \alpha_1 + \alpha_2$, because output increases by the factor r of input expansion. There are increasing returns to scale for $r > 1$, constant returns to scale for $r = 1$, and decreasing returns to scale for $r < 1$. The notion economies of scale describes $r - 1$. They are positive for $r > 1$, zero for $r = 1$, and negative for $r < 1$.

The general cost function is:

$$(2.2) \quad C = P_1 x_1 + P_2 x_2,$$

where P_1, P_2 are the prices of inputs 1 and 2.

In order to transfer (2.2) into a cost function that can be estimated, first cost minimization subject to (2.1) is assumed.

$$(2.3) \quad \min_{x_1, x_2} L = P_1 x_1 + P_2 x_2 + \lambda \left(Y - A \cdot x_1^{\alpha_1} x_2^{\alpha_2} \right).$$

Solving the Lagrangian for x_1 and x_2 yields:

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15 See also Berndt (1991, pp. 66-81) and Backus et al. (1992) for a description and derivation of different types of EOS.

$$(2.4) \quad x_1 = \frac{\alpha_1}{\alpha_2}\frac{P_2}{P_1} \cdot x_2,$$

$$x_2 = \frac{\alpha_2}{\alpha_1}\frac{P_1}{P_2} \cdot x_1$$

Plugging expression (2.4) into the production function and rearranging terms yields:

$$(2.5) \quad x_1 = \left[\frac{Y}{A}\left(\frac{\alpha_2}{\alpha_1} \cdot \frac{P_1}{P_2}\right)^{-\alpha_2}\right]^{1/r}$$

$$x_2 = \left[\frac{Y}{A}\left(\frac{\alpha_1}{\alpha_2} \cdot \frac{P_2}{P_1}\right)^{-\alpha_1}\right]^{1/r}$$

Plugging these expressions into the cost function (2.2) and rearranging terms yields:

$$(2.6) \quad C = r\left(A\alpha_1^{\alpha_1}\alpha_2^{\alpha_2}\right)^{-1/r}\left(Y \cdot P_1^{\alpha_1}P_2^{\alpha_2}\right)^{1/r}.$$

This function is dependent on prices and output only. Defining $k = r\left(A\alpha_1^{\alpha_1}\alpha_2^{\alpha_2}\right)^{-1/r}$, taking logarithms and including a stochastic disturbance term (μ), it can be transferred into a log linear function, which can be used to estimate static InEOS:

$$(2.7) \quad \ln C = \ln k + \frac{1}{r}\ln Y + \frac{\alpha_1}{r}\ln P_1 + \frac{\alpha_2}{r}\ln P_2 + \mu.$$

Estimating dynamic InEOS aims at describing cost reductions due to learning effects through cumulative production. These effects can be included in the production function by specifying the productivity term as $A_t = A' \cdot n_t^{\alpha_c}$, where n_t is the amount of cumulative output produced up to but not including time t, α_c is the elasticity of unit costs with respect to cumulative output and A' is the general productivity parameter net of learning effects. The log linear cost function is now described by:

$$(2.8) \quad \ln C = \ln k' + \frac{\alpha_c}{r} \cdot \ln n_t + \frac{1}{r} \ln Y + \frac{\alpha_1}{r} \ln P_1 + \frac{\alpha_2}{r} \ln P_2 + \mu,$$

where $k' = r\left(A' \alpha_1^{\alpha_1} \alpha_2^{\alpha_2}\right)^{-1/r}$.

Making the assumption that the change in the two price terms of equation (2.8) can be measured by the GNP deflator, and subtracting the price terms on both sides, yields an expression for real costs. By further subtracting $\ln Y_t$ from both sides, real unit costs can be expressed as:

$$(2.9) \quad \ln c = \ln k' + \frac{\alpha_c}{r} \cdot \ln n_t + \left(\frac{1-r}{r}\right) \cdot \ln Y_t + \mu.$$

Equation (2.9) is the cost function that can be estimated including static and dynamic InEOS, where $\ln k' = \ln c_1$ can be regarded as the costs of the first unit produced. If the restriction of constant returns to scale, i.e., $r = 1$, cannot be rejected, one arrives at the learning curve function as usually estimated in the literature:

$$(2.10) \quad \ln c_t = \ln c_1 + \alpha_c \ln n_t + \mu.$$

The equation implies that if cumulative output increases by a factor n, costs decrease to n^{α_c} percent of their previous level. To standardize a measure for cost reductions, the learning curve is commonly said to have a d percent slope if cumulative output doubles, i.e. $n = 2$, such that $d = 2^{\alpha_c}$.

The estimation of static ExEOS works in a similar way as the estimation of dynamic InEOS. With static ExEOS, productivity increases, i.e. unit cost decrease, with the amount of production of others but the own firm at a point in time. In the case of localization EOS, productivity is dependent on the number of firms of the same industry. In the case of urbanization EOS, firm productivity depends on the output of all industries but the own industry. The productivity term can be specified to be:

$$(2.11)\quad A = A'\left(\sum_{\substack{i=1 \\ i\neq i}}^{N} Y_{ij}\right)^{\rho}\left(\sum_{\substack{j=1}}^{M}\sum_{i=1}^{N}{}_{j\neq j} Y_{ij}\right)^{\gamma},$$

where Y_{ij} denotes output of firm i in industry j, ρ is the elasticity of productivity towards own industry output, γ is the elasticity of productivity towards output of other industries, and A' is again a general productivity term net of these effects.

Specifying the cost function (2.6) by expression (2.11), the log linear form can be used to test for the existence of LocEOS and UrbEOS by:

$$(2.12)\quad \ln C = \ln k' + \frac{\rho}{r}\left(\sum_{\substack{i=1\\ i\neq i}}^{N} Y_{ij}\right) + \frac{\gamma}{r}\left(\sum_{\substack{j=1\\ j\neq 1}}^{M}\sum_{i=1}^{N} Y_{ij}\right) + \frac{1}{r}\ln Y + \frac{\alpha_1}{r}\ln P_1 + \frac{\alpha_2}{r}\ln P_2 + \mu$$

and $\quad k' = r\left(A'\alpha_1^{\alpha_1}\alpha_2^{\alpha_2}\right)^{-1/r}$.

For $\rho \neq 0$, and $\gamma \neq 0$ the existence of localization and urbanization EOS is confirmed.

Dynamic ExEOS influence the growth rate of the productivity parameter. In the presence of MAREOS, productivity growth depends positively on the output of all firms of the own industry in the region. In the presence of JaEOS, productivity growth depends positively on the output of all industries but the own industry in the region. Productivity growth can be expressed as:

$$(2.13)\ \Delta A = \Delta A'\left(\sum_{\substack{i=1\\ i\neq 1}}^{N} Y_{ij}\right)^{\beta}\left(\sum_{\substack{j=1\\ j\neq 1}}^{M}\sum_{i=1}^{N} Y_{ij}\right)^{\sigma},$$

where β is the elasticity of productivity towards own industry output, σ is the elasticity of productivity towards all, but the own industry output, and $\Delta A'$ is the productivity growth net of these effects.

Using production function (2.1), output growth can be decomposed into productivity growth and input growth. Taking (2.13) as a description of productivity growth and including a stochastic disturbance term, one arrives at:

$$(2.14)\quad \ln \Delta Y = \ln \Delta A' + \beta \ln \left(\sum_{\substack{i=1 \\ i \neq 1}}^{N} Y_{ij} \right) + \sigma \ln \left(\sum_{\substack{j=1 \\ j \neq 1}}^{M} \sum_{i=1}^{N} Y_{ij} \right) + \alpha_1 \Delta \ln x_1 + \alpha_2 \Delta \ln x_2 + \mu .$$

For $\beta \neq 0$, and $\sigma \neq 0$ the existence of MAREOS and JaEOS is confirmed.

Empirical studies as those surveyed in the next two chapters often use different equations than (2.7), (2.9), (2.12) and (2.14) to estimated EOS. This can be due to the use of different production functions, the inclusion of further regressors or the adjustment to specific data sets. The underlying principles of modeling various forms of EOS, however, remain the same.

3. Internal Economies of Scale

3.1 Estimating Static Internal Economies of Scale

The estimation of static InEOS faces severe difficulties. The length of the production run cannot easily be extended or reduced for experimental purposes for a large number of firms, such that the degree of EOS can be measured accurately. Therefore, often auxiliary measures instead of econometric estimates are taken as an assessment of the importance of InEOS. Strong InEOS favor large firms, oligopolistic market structures and the concentration of production. Hence, the following four indicators are often used as an indirect measure of the strength of EOS in an industry. The *Price-Cost Margin* also called the *Lerner Index* is calculated as price minus marginal cost divided

by average cost. It indicates the degree of marked power of a firm within an industry. The *n-Firm Concentration Ratio* shows the proportion of total sales in the industry accounted for by the *n* largest firms. The *Herfindahl-Hirschman Index* is the sum of the squared market shares of all firms in the industry and increases with higher concentration of production.

Comparability of firm level EOS is further complicated if firms operate with a different scale of production at which the degree of EOS is estimated, because the degree of EOS varies with the level of output at which they are measured. In the presence of fixed costs, the average cost curve is downward sloping even for constant marginal costs, because average fixed costs decline. Then, the reduction of unit costs from increasing output by a given absolute level is highest at low levels of output. If so, scale economies may be more relevant for small firms and may already be more exploited by large firms. Therefore, Bain (1956) suggested to measure the degree of InEOS at a fixed point of the long run average cost curve. This could be 1/3 or 1/2 of the *Minimum Efficient plant Size* (MES). The MES is the size of the firm at which the long run average cost curve starts being flat such that a doubling of output leads to an insignificant reduction of unit costs, say by less than 5 percent. The degree of InEOS is then measured by the increase of unit costs from the MES to 1/3 or 1/2 of MES. Furthermore, the MES itself is a measure of EOS, because high MES point to a reduction of unit costs over a large range of output.

The three approaches most commonly used to assess and estimate direct or indirect measures of static InEOS are the survivor technique, econometric estimates of profit and cost functions and engineering estimates.[16] In this section, I focus mainly on econometric and engineering estimates, since these approaches are able to yield exact estimates about the size of InEOS. In contrast, the survivor technique is often used as a first measure to assess the size structure in an industry before more rigorous econometric approaches are applied. The technique has been suggested by Stigler (1958). He argues that instead of estimating potential costs at different levels of output it would be more appropriate to check whether firms at different sizes are able to survive. The optimal firm level can be seen from the growth rates of firms at different size groups. He suggests: "Classify the firms in an industry by size and calculate the share of industry output coming from each class over time. If the share of a given class falls it is relatively inefficient and in general is more inefficient the more rapidly the share falls" (p. 54). If a class of firms is able to survive it will have at least MES. The survivor test has the advantage that its costs are much lower than that of other

16 MacPhee and Peterson (1990) is the only study I am aware of that compares the results of engineering, econometric and survivor approaches. For a comparison they chose the US flour milling, cheese, and fluid milk industries over the years 1958 to 1982. They find that all techniques lead to similar results.

approaches. This is true for data collecting as well as data processing.[17] The problem that Stigler himself found is that a large range of firm sizes passes the survivor test which indicates low InEOS. The survivor test might also be biased because it cannot control for other influences than size by including further explanatory variables like heterogeneity of inputs, the quality of the management, or the size of the market. Similar to the specialization of production, optimal firm size is also an increasing function of the size of the market, reflecting trade costs rather than scale efficiency (Berry, 1992). Also, the process of firm shrinkage and growth is a very gradual one. As firms start small and grow, the size structure in an industry also reflects its historical life pattern instead of its possibility to survive. It might also be that the optimal technology varies with other characteristics of a firm and optimal size is a function of technology. If also firm size varies in the product cycle, there might be firms with non-frontier technologies that should not change their size until the existing technology has been depreciated, which might bias firm size classes further.

17 Stigler applies the test to 48 three digit US industries, and calculates optimum firm sizes for each of them. He finds that the optimum size has a fairly wide range. This let him conclude that the average cost curves for firms are horizontal over a long range of firm size. Saving (1961) found that over half of US industries for which he made survivor test for 1947-1954 had a MES of maximal 1 percent of the industry size, which also indicates an early flattening out of the average costs curve. Other early applications of the survivor technique are Weiss (1964), Shepherd (1967), who provides estimates for 117 industries, and Rees (1973). More recent ones are Pickford (1984), Keeler (1989), and Rogers (1993). Hibdon and Mueller (1990) show that using annual data over the period 1947-1984 changes Stiglers results in the petrolium refining industry and leads to a declining long run cost curve. Eisen (1994) studies the optimal firm size in the life insurance buisness. He finds that the optimal firm size is streched over a fairly large range, which contradicts the hypotheses that scale economies determine firm size in the insurance business. He notes that regional markets, specialization of small firms on specific products and market niches may explain that firms of different sizes are able to survive.

Econometric estimates

Another method of estimating InEOS is the comparison of costs or profits of firms in an industry at different scales of output on the basis of cross-section, time series and panel data. Probably the best studied industrial sector is the electric power generation, where most studies find considerable InEOS. These, however, may change over time. For instance, Christensen and Green (1976) analyze InEOS with cross-section data for US electric power firms. While significant unrealized scale economies could be found in 1955, most firms were operating at the flat part of the average cost curve in 1970. For further references see the surveys by Cowing and Smith (1978) and Jorgenson (1986, pp. 1893- 1897).

Lyons (1980) estimates MES of firms in 118 UK trades. He finds that for most trades MES is below 250 employees, which indicates rather small InEOS. Griliches and Ringstad (1971) and Ringstad (1978) analyzed manufacturing industries in Norway. From the data on more than 5000 firms, they find evidence for small economies of scale in the range of 4 percent that are not very sensitive to the production function used, and showed little differences across industries. The authors point out that the estimates may be uncertain, albeit it is equally well possible that they are too low or too large. Baldwin and Gorecki (1986) estimate cost and production functions for Canadian industries on the 4 digit level. For 1979 they find returns to scale to average approximately 10 percent for 107 manufacturing industries. Highest

InEOS were found in tobacco, non-metallic mineral goods and food and beverages, whereas low InEOS were found in clothing manufacture, knitting, leather and textiles.

Owen (1983) estimates InEOS using price and cost data for the European car, truck and consumer durables industries. He finds costs reductions due to an increase of output, but does not distinguish between static and dynamic InEOS. Little, Mazumdar and Page (1987) analyze the relationship between firm size and factor productivity in five Indian industries. With the exception of machine tool manufacturing no InEOS could be found once technical efficiency was controlled for by the average experience of the labor force, the age of the capital stock, the experience of the entrepreneur and the level of capacity utilization. Scherer (1980, p. 92) presents profit rates for small and large US firms for the 1960s and the 1970s. He finds evidence that larger firms have higher profit rates, but these estimates may be biased upwards due to variations across size categories in the accounting conventions involving depreciation. Marcus (1969) finds no clear relationship between size and profitability in the US. Some industries are characterized by positive, others by negative and others by no relationship between size and profitability.

Panel data analyses that have been used by Westbrook and Tybout (1993) and Tybout and Westbrook (1992) to analyze scale effects in Chilean and Mexican manufacturing firms of different three digit industries. Westbrook and Tybout (1993) find returns to scale to vary between 0.8 and 1.2 between different industries. However, the coefficients are not statistically different from 1, i.e. constant returns to

scale. These estimates abstract from fixed costs, which may be a strong source of InEOS. Tybout and Westbrook (1992) find scale effects of more than 2 percent in only 3 of 20 industries. They use several estimators, notably OLS, between estimators, within estimators, j^{th} difference estimators each with and without instrumental variables. The properties of these estimators are discussed in length in Tybout and Westbrook (1993) and are summarized in Table 1. The table suggests that instrumental variable estimators - including method-of-moments estimators - are the most appropriate estimators, because they consider sunk costs, and they are not biased by unobserved firm effects and measurement error. However, it is usually impossible to find appropriate instruments.

Table 1 — Sources of Bias for the Estimators

Estimator	Capture sunk costs	Biased due to unobserved plant effects	Biased due to measurement error
OLS	yes	yes	yes
Between	yes	yes	yes but attenuated
Within	no	no	yes, possibly exacerbated
j^{th} Difference	no	no	yes, possibly exacerbated
Instrumental variables OLS	yes	no	no
Instrumental variables between	yes	no	no
Instrumental variables within	no	no	no
Instrumental variables j^{th} difference	no	no	no

Source: Tybout and Westbrook (1992).

Using Census data to estimate the relationship of costs or profitability on the one side and the scale of output on the other side has several further drawbacks. The definition of most Census trades includes the production of a broad range of goods for

which InEOS and other characteristics like market size and growth may vary substantially. The estimates may also reflect influences of varying relative factor prices at different output levels. An omitted variable problem arises when trying to sort out cost savings associated with scale from those due to other possible sources. For example, lower costs and higher profits may also be caused by higher monopoly power of larger firms. Profits are often lower in smaller firms not because of lower efficiency, but because owner-managers, pay themselves higher salaries in order to avoid double taxation. Small firms do better in booms than large firms and less well in throughs reflecting a less diversified product and consumer structure, and larger firms have more possibilities to smooth reported earnings in their accounts. For the empirical analysis the main problem is how to measure the cost decrease. Actual observations also include the impact of other variables like product heterogeneity, differences of capital vintages between firms within an industry, and the quality and prices of the factors of production. Cost data may understate InEOS, because competitive pressure eliminates a higher share of actual or latent smaller firms than larger ones. Since only the most efficient small firms are able to survive, the sample is biased, which leads to a weaker observed size cost relationship than that implied in the technology.[18]

Another part of the literature on InEOS relies on Hall (1988, 1990). Hall observes that prices differ substantially from marginal cost in US industries, and that the Solow

[18] See Berry (1993) for a thorough discussion of the complications when relating firm size and economic efficiency.

residual fails to be uncorrelated with product demand and factor price movements. He discusses several possible explanations of the failure of this invariance property. Hall concludes that the most likely is monopolistic competition and increasing returns, both of which contradict the crucial assumptions of Solow's approach to measure productivity growth. He develops a method to derive an index of returns to scale and estimates of mark-ups over marginal costs. Using value added data for US manufacturing, he estimates mark-ups for 26 two digit industries and finds returns to scale to exceed 1.5 in all of them but services.[19] His approach has been adopted and further developed by Caballero and Lyons (1989, 1990, 1992) and Bartelsman, Caballero and Lyons (1994). Caballero and Lyons include a measure for aggregate manufacturing in Hall's approach. This enables them to distinguish between internal and external EOS. In their study internal EOS refer to productivity increases due to industry wide output expansion; thus, captures something in between InEOS and LocEOS in my classification. They find no increasing internal returns, but a positive correlation between productivity in a specific industry and overall industrial activity. They conclude that external EOS rather than internal EOS are the most important reason for the failure of the invariance of the Solow residual. The use of value added data in these studies has been criticized by Basu and Fernald (1995). They show that with imperfect competition value added data biases the estimates so that one finds

[19] See Domowitz et al. (1988) and Shapiro (1987), who also report strong market power in numerous US industries and significant departures of competition.

large apparent externalities even if they do not exist. Instead output data should be taken. Using gross output data for 21 two digit US manufacturing industries, they find little or no significant effects of an increase of output in one manufacturing sector on the productivity of other sectors.[20] [21] Hall's approach has been further developed by Roeger (1995) who controls for the possible presence of imperfect competition. By considering positive mark-ups over marginal costs, he is able to show that over 90 percent of the difference between primal and dual productivity measures can be explained by imperfect competition. As a by-product he gets mark-up estimates for US manufacturing industries. His estimates are considerably lower than Hall's and lie between 15 percent in apparel and 214 percent in the electric, gas and sanitary services industry. Oliveira Martins et al. (1996) further extend Roeger's method by including intermediate inputs. This makes it possible to estimate mark-ups by using output instead of value added data. This removes the upward bias of the estimation with value added data (Basu and Fernald, 1995). Oliveira Martins et al. (1996) use the OECD Stan-database to estimate mark-ups for 19 OECD countries and 36 manufacturing sectors at the 3-4 digit level. Figure 2 summarizes their results. It can be seen that

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20 However, Oulton (1996) confirms the results of Caballero and Lyons by the use of gross output data for the UK. He finds externalities of an expansion of aggregate manufacturing output, but no externalities of sectoral output. On the industry level returns to scale appear to be constant.

21 Burnside et al. (1995) and Burnside (1996) argue that the evidence for increasing returns based on Hall's approach is not convincing because they do not control for the cyclical variation in the utilization of capital, and impose non-justified cross-industry equality restrictions on the parameters. Burnside's most robust evidence suggests that the typical US manufacturing industry displays constant returns with no external effects. However, he acknowledges that there is significant heterogeneity across industries.

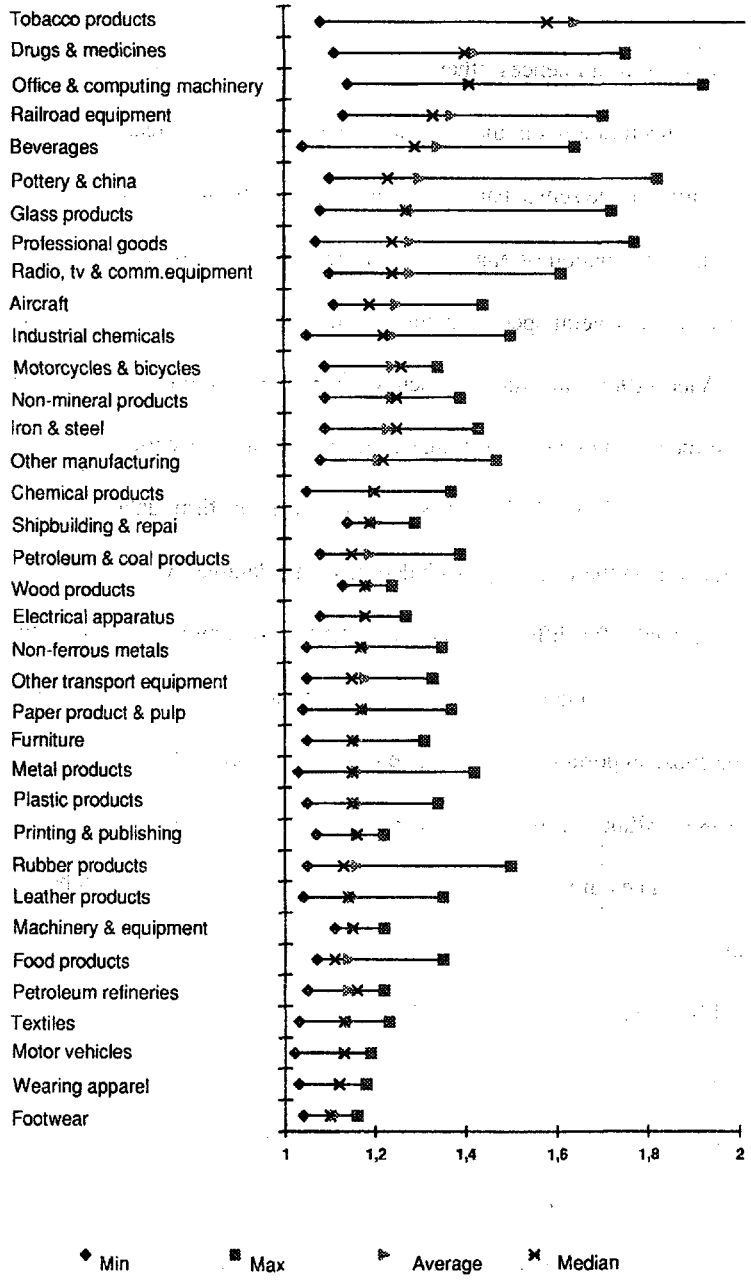
mark-ups vary considerably between industries and countries. Highest mark-ups were estimated for tobacco products, drugs and medicines, office and computing machinery, while lowest mark-ups were estimated for footwear, wearing apparel, and motor vehicles.

Summing up, most econometric studies find positive economies of scale. However, there are several difficulties with econometric estimates. Estimates of mark-ups seem to yield robust evidence for the departure of perfect competition and marginal cost pricing, which supports the hypothesis of the importance of InEOS. However, it should be noted that, while these studies estimate the importance of firm level EOS, they do not use firm level but industry level data in their estimation.

Engineering estimates

In order to circumvent the problems that arise with real data, the engineering approach takes hypothetical data for costs at different output levels in order to construct engineering cost functions. In this approach, estimates of cost levels at different scales of production made by managers, engineers, economists and accountants are assembled. Scientific laws, experimental data and process costs are taken together to estimate a relationship of unit costs and the scale of production. This gives a calculation of probable costs of enterprises of different sizes. The advantage of this approach is that it is able to focus on the specific production process where it can

Figure 2: Estimated Sectoral mark-ups for 14 OECD countries



Source: Oliveira Martins, Scarpetta and Pilat (1996).

abstract from influences other than scale, such as relative prices and learning effects. The concentration on the technical aspects of an increase in output increases its reliability in the sense that it is not biased by other influences.

The construction of engineering production functions goes back to Chenery (1949). Since then, several specific industry studies have been performed. These are surveyed in Wibe (1984) and further discussed in Smith (1986) and Wibe (1986). One of the first more comprehensive studies of InEOS using engineering data was Pratten (1971). He examined plant size EOS on the basis of firm data from 28 manufacturing industries in the UK, and concluded that considerable EOS exist. These, however, vary substantially for different industries. The most comprehensive evidence on InEOS has been collected again by Pratten (1988). He summarizes numerous studies, out of which the most important may be Pratten (1971), Scherer (1975, 1980), Müller and Owen (1983), Müller et al. (1985), Weiss (1976) and Connor et al. (1984). The results of these studies are presented in Tables 2-4. Table 2 shows branches of manufacturing industry ranked by their approximate size of InEOS, which has been measured at 1/2 MES. Very high degrees of InEOS were found in motor vehicles, other means of transport, chemicals, machinery and instrument manufacturing, and paper and printing. Emerson (1988) concludes that InEOS are an important characteristic in the production of EU industrial goods since over 50 percent of the EC 12s industrial production takes place in these branches. This is confirmed by Prattens' (1988) calculations of the percentage of MES of UK and EC output. From this percentage the sustainable

number of firms in an industry can be concluded. High percentages indicate high InEOS independent of the elasticity of output to an increase in inputs at MES. Pratten (1988) shows that for several industries MES are too high to support more than a few firms in the UK. 27 percent of EC output is produced in industries whose MES is above 5 percent of the whole EC market. Consequently, in the long run these industries support at most 20 firms EC wide.

InEOS were lowest or non-existent in the branches of leather and leather goods, footwear and clothing, timber and wood as well as the textile industry. Low InEOS prevail in food, drink and tobacco, and rubber and plastics. Table 2 also shows that the cost reductions at 1/2 MES vary substantially in different subsectors of the branches. Table 3 shows the distribution of extra costs in per cent that arise from a firm size below 1/2 of MES. The table shows that InEOS were in the range of 2-15 percent for most of the 45 firms for which a cost gradient was available. Product groups on the 3 digit level of the NACE Code for which InEOS are superior or equal to 10 per cent are shown in Table 4. The highest levels of InEOS can be realized in books, bricks, dyes and aircraft.

These estimates are no fixed technical relationship or a common law. MES firm sizes change over time and are different in different countries. For example Sands (1961) found that MES increased by about 3 percent on average of 46 industries between 1904 and 1947. Schwalbach (1988) shows that average firm size in Germany,

Table 2 — Branches of Manufacturing Industry Ranked by Size of Economies of Scale

NACE Code	Branch	Cost gradient at half MES (percent)	Remarks
35	Motor vehicles	6-9	Very substantial EOS in production and in development costs.
36	Other means of transport	8-20	Variable EOS: small for cycles and shipbuilding (although economies are possible through series production level), very substantial in aircraft (development costs).
25	Chemical industry	2.5-15	Substantial EOS in production processes. In some segments of the industry (pharmaceutical products), R&D is an important source of EOS.
26	Man-made fibres	5-10	Substantial EOS in general.
22	Metals	>6	Substantial EOS in general for production processes. Also possible in production and series production.
33	Office Machinery	3-6	Substantial EOS at product level.
32	Mechanical engineering	3-10	Limited EOS at firm level but substantial production.
34	Electrical engineering	5-15	Substantial EOS at product level and for development costs.
37	Instrument engineering	5-15	Substantial EOS at product level, via development costs.
47	Paper, printing and publishing	8-36	Substantial EOS in paper mills and, in particular, printing (books).
24	Non-metallic mineral products	>6	Substantial EOS in cement and flat glass production processes. In other branches, optimum plant size is small compared with the optimum size for the industry.
31	Metal articles	5-10 (castings)	EOS are lower at plant level but possible at production and series production level.
48	Rubber and plastics	3-6	Moderate EOS in tire manufacture. Small EOS in factories making rubber and molded plastic articles but potential for EOS at product and series production level.
41-42	Drink and tobacco	1-6	Moderate EOS in breweries. Small EOS in cigarette factories. In marketing, EOS are considerable.
41-42	Food	3.5-21	Principal source of EOS is the individual plant. EOS at marketing and distribution level.
49	Other manufacturing	n.a.	Plant size is small in these branches. Possible EOS from specialization and the length of production runs.
43	Textile industry	10 (carpets)	EOS are more limited than in the other sectors, but possible economies from specialization and the length of production runs.
46	Timber and wood	n.a.	No EOS for plants in these sectors. Possible EOS from specialization and the length of production runs.
45	Footwear and clothing	1 (footwear)	Small EOS at plant level but possible EOS from specialization and longer production runs.
44	Leather and leather goods	n.a.	Small EOS.

Source: Pratten (1988), cited from Emerson et al. (1988).

Table 3 — Supplementary Costs Borne for a Plant Size Below 50 Percent of the Minimum Efficient Size (MES)

Extra costs (as percent)	Distribution of sample (percent)
0-2	4
2-5	36
5-10	29
10-15	24
15-20	2
20-25	2
25 and over	2

Source: Pratten (1988, p. 82).

Table 4 — Products for which the Cost Slope below 50 Percent of the Minimum Efficient Size (MES) is Superior or Equal to 10 Percent

NACE Code	Product	Cost gradient at 1/2 MES
473	Books	20-36
241	Bricks	25
251	Dyes	17-22
364	Aircraft	20
251	Titanium oxide	8-16
242	Cement	6-16
251	Synthetic rubber	15
342	Electric motors	15
471	Kraft paper	13
251	Petrochemicals	12
26	Nylon	12
311	Cylinder block castings	10
311	Small cast-iron castings	10
438	Carpets	10
328	Diesel engines	10

Source: Pratten (1988).

Italy and the UK is considerably smaller than the MES, which leads to higher production costs of up to 25 percent. The gains from European integration depend in how far these EOS are realized. If production can indeed be expanded to MES, productivity gains are huge.

The disadvantage of engineering estimates is the lack of familiarity of managers and engineers with what happens if firms are operated at a different size than the one being used. Thus, they are subjective to a certain extent. It is also often difficult to get reliable and comparable information. Since the sources are interviews and questionnaires the approach is associated with high costs both for the informants and the informer. It lacks the rigor of other approaches that can be tested by statistical and econometric methods. Additionally, engineering data tend to show greater cost reductions with size than do cost or profit data. Berry (1992) argues that engineers may hold constant the technology across size of potential firms, although lower-cost technologies may exist for lower or higher levels of output. This may bias costs estimates for output levels above the current output level of the firm.

3.2 Estimating Dynamic Internal Economies of Scale

Empirical studies of dynamic InEOS or learning effects go back to Wright (1936). He found that the productivity of aircraft production increases with firm cumulative output. Such learning curve effects have been surveyed by Argote and Epple (1990), and extensively studied by Ghemawat (1985).[22] Ghemawat compiled 97 studies that analyze learning effects for 102 manufacturing products. A summary of these studies is given in Table 5. The average elasticity of unit costs with respect to cumulative output

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22 See also Berndt (p. 66) for further references on the estimation and interpretation of learning curve effects.

is 0.31, which translates into a slope of the learning curve of 0.81 per cent. Consequently, unit costs decline on average to 81 percent of their previous level if cumulative output doubles.

Table 5 — Learning Curve Elasticity Estimates for Manufacturing Products

Number of products	Learning curve elasticity ($-\alpha_c$)	Learning curve slope (d)
3	0.62-0.74	0.60-0.65
3	0.51-0.62	0.65-0.70
10	0.41-0.51	0.70-0.75
23	0.32-0.41	0.75-0.80
30	0.24-0.32	0.80-0.85
26	0.15-0.24	0.85-0.90
6	0.08-0.15	0.90-0.95
1	0.00-0.08	0.95-1.00
Average:	0.31	0.81

Data Source: Ghemawat (1985).

Learning effects vary according to different sectors. Table 6 shows sectors where the highest learning effects can be realized according to Emerson (1988, p. 138). These are electronic components and microcomputing. As it seems, learning effects are the stronger, the higher is the share of labor, especially skilled labor, and the lower is the share of machinery costs in manufacturing. Ghemawat (1985, p. 144) concludes that "manufacturing activities encounter steeper learning curves than raw materials purchasing, marketing sales or distribution". This reflects that in the early stages of a products' life cycle, the most significant gains can be experienced by cumulative production.[23] The semiconductor industry is often cited as the prime-industry for learning by doing effects. Irwin and Klenow (1994) use quarterly firm data for the

23 See also Emerson (1988, pp. 137-140).

period 1974-1992 to assess learning effects of seven semiconductor generations. They find that the fall in unit costs due to an increase in cumulative output is as high as 10 percent to 27 percent. Intergenerational spillovers are weak or non-existent, indicating that a comparative advantage in the production of one semiconductor generation does not imply a strategic asset in the sense that it may lead to a long lasting competitive advantage in future semiconductor generations. Additionally, Irwin and Klenow find that firms learn three times more from an increase in their own cumulative production than from an increase from other firms cumulative production.

Table 6 — Examples of Total Unit Cost Reduction Observed for Various Activities as a Result of Doubling Cumulative Production

Industry or service sector	Fall in unit costs as a result of cumulative production being doubled
Electric components	30
Microcomputing	30
Ball-bearings	27
Industrial Plastics	25
Equipment maintenance	24
Life insurance	23
Aerospace	20
Electricity	20
Starters for motor vehicles	15
Oil refining	10

Source: Emerson (1988, p. 138).

3.3 The Empirical Relevance of Internal Economies of Scale

Despite many methodological reservations, taken together the previous two sections document the existence of InEOS. The findings have an implication for the modeling of market structures. That is, the macroeconomic models of section 2.3 that give up the assumption of constant returns and perfect competition are in line with the empirical findings on InEOS. However, the question remains whether the inclusion of EOS adds to the explanation of the economic phenomena under study. Put differently, the inclusion of InEOS does not necessarily mean that they have a large quantitative role to play. Thus, this section examines the empirical relevance of InEOS.

International trade may be the field in which the inclusion of InEOS has the most direct theoretical impact. The large share of intra-industry trade in total trade is difficult to explain by traditional trade theories. Therefore, most modern approaches rely on preferences for variety and InEOS. With preferences for variety, as many goods as possible are consumed. Fixed costs of production limit the number of goods that a country can produce. Hence, products from one's own and from all other countries are bought. Trade costs, however, ensure that the consumption of each home variety is higher than the consumption of foreign varieties. Large countries produce with a larger scale of output than small countries. In turn, a larger scale of output is associated with lower average costs. The higher are fixed costs and InEOS, the smaller is the number of goods produced in a country and the higher is import demand. This leads to two testable hypotheses. First, large countries have a comparative advantage

in goods subject to large InEOS (Helpman and Krugman, 1985, chap. 10). Second, the volume of intra-industry trade rises with the degree of InEOS.

Torstensson (1995) tests the first hypothesis with OECD data for 23 countries and product groups at the 4-digit level of ISIC. He finds no evidence that countries with larger domestic markets are net exporters in industries that are characterized by InEOS. However, he states that his results are sensitive to the proxy variable used to measure the degree of InEOS. Auguier (1980), Glejser et al. (1980), Tyler (1976) and Roberts and Tybout (1991) find that exporters are typically larger than firms oriented toward the home market only. Above that Schwalbach (1988), Owen (1983), Müller and Owen (1985) and Scherer et al. (1975) find that firm sizes are positively correlated with export activities even if controlling for domestic market size. Banerji (1978), Caves (1984), Baldwin and Gorecki (1986) and Schwalbach (1988) report that home market size is correlated with average firm size, so that large domestic markets seem to yield a competitive advantage for export activities, giving support to the first hypothesis. However, Krugman (1984) and Tybout (1993) argue that independent from InEOS, low marginal costs always lead to higher exports. In turn, low marginal costs may result from other sources like cross-firm differences in learning by doing, R&D spillovers, other regional externalities or more modern technologies.

Concerning the second hypothesis, empirical studies find no robust relationship between scale and intra-industry trade.[24] Leamer (1992) finds that constant returns to scale cannot generally be ruled out. Then, trade also could be explained by Armington preferences, where consumers simply distinguish between home and foreign consumer goods. However, Harrigan (1994) argues that most previous empirical evaluations of intra-industry trade models failed because of incorrectly regressing Grubel and Lloyd indices on various proxies for scale economies. He argues that the Grubel and Lloyd index does not necessarily vary with the degree of EOS. Instead he proposes a model to distinguish between an Armington type explanation for intra-industry trade and increasing returns type explanations. Using the four different measures for InEOS discussed beginning of section 3.1. and 1983 OECD data for 26 countries, Harrigan finds some evidence that the volume of trade is higher in sectors with high InEOS. However, the results are quite sensitive to the choice of the proxy of InEOS. He concludes that "product differentiation by location of production is an important cause for trade, and that international exploitation of scale economies may also contribute importantly to the volume of trade" (p. 327).

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24 See Leamer and Levinsohn (1995) and Hummel and Levinsohn (1995) for an overview of the empirical literature on international trade theory. They report little evidence that scale economies provide an important determinant of trade. This might partly be due to the low robustness of possible determinants of intra-industry trade. Torstensson (1996) performs a sensitivity analysis of possible intra-industry trade determinants and finds that most variables are rather fragile and sensitive to different specifications and measurement.

The second hypothesis that intra-industry trade shares rise with the degree of InEOS reflects a wide belief that the reduction of trade costs leads to further exploitation of InEOS. This has served as an argument for the completion of the single European Market. The theoretical idea behind this argument is that the availability of further foreign varieties increases the elasticity of demand of a domestic consumer. Under monopolistic pricing, this raises the optimal scale of output of a firm, lowers average costs and, hence, further exploits InEOS. However, empirical evidence on further realized InEOS, supporting this hypothesis for the case of the EU is not available. Tybout and Westbrook (1995) test the same hypothesis for Mexican industries. They find only minor gains due to the exploitation of InEOS after Mexico's trade liberalization in 1985. Productivity did increase due to capacity utilization, economies of scope, elimination of waste, and external economies, instead of due to the exposure to foreign competition.

Davis and Weinstein (1996) use a model that nests an economic geography model with InEOS into the neoclassical Heckscher-Ohlin framework. They find that 90 percent of the explainable trade specialization can be traced back to endowment differences and at most 10 percent may be due to economic geography. In contrast, Brülhart and Torstensson (1996) find employment in scale intensive industries to be concentrated in the center of the EU, supporting the importance of InEOS for the location of industries and trade patterns.

Summing up, one can say that the evidence on the quantitative importance of InEOS for the explanation of real economic phenomena is far less clear than one would expect from the theoretical contributions to the fields. Empirical evidence is mixed with regard to the relevance of InEOS in explaining patterns of production and trade across countries.

4. External Economies of Scale

4.1 Estimating Static External Economies of Scale

Several approaches have been used to estimate static ExEOS. Some studies analyze whether concentration of economic activity raises productivity per se, some estimate how much productivity declines with rising distance from the center. Others distinguish between localization and urbanization externalities. Thus, the empirical work dealing with static ExEOS can be broadly divided into papers that focus on the existence, the extent and the nature of ExEOS. Papers analyzing the extent of ExEOS and estimates of their productivity increasing effects are presented in section 4.3 with the relevance of ExEOS.

Papers that test the existence of static ExEOS are, for instance Carlton (1983) and Wheeler and Mody (1992). In estimating investment and location decisions of US firms, they include a term approximating agglomeration economies. They find that industrial concentration is advantageous for the location of further firms. Similar approaches have been adopted by Carlino (1979), Hay (1979), Moomaw (1981) and

Shefer (1973), who also find evidence for agglomeration economies. Moomaw (1983), Segal (1976) and Sveikauskas (1975) use production functions to estimate the impact of urban size on industrial productivity, which comes out to be positive up to a certain city size. Head et al. (1994) analyze investment decisions in the US. However, they try to sort out endowment differences of different states in order to isolate spillover effects. They find that Japanese manufacturing investment is likely to be located near other Japanese firms of the same industry, and does not simply mimick the geographical pattern of US firms in their industry. They also find that the observed spillovers do not stop at state borders. Smith and Florida (1994) come to similar results, analyzing the location of Japanese affiliated manufacturing establishments in automotive related industries. They find that these firms reveal strong preferences for locations with other Japanese automotive assemblers, holding constant several other determinants. From this, they conclude the importance of backward and forward linkages as sources of agglomeration economies.

Another group of papers examines the nature of agglomeration economies. That is, they estimate whether urbanization or localization economies prevail. This is important in order to assess whether specialized or diversified cities lead to the most efficient division of production. For instance, the former socialist countries apparently believed in localization economies and, therefore, created large monostructured regions. Greytak and Blackley (1985), Henderson (1986), Nakamura (1985) and Sveikauskas (1988) assess the relative importance of urbanization and localization economies.

Henderson (1986) analyzed cross-sectional data for the US and Brazil to estimate the nature and extent of ExEOS. He finds that ExEOS are in general more due to localization than to urbanization. The specialization of a city leads to localization externalities, which, however, peter out with an increase of city size. Since ExEOS peter out, one should expect small and medium size cities to be more specialized than larger cities. Nakamura (1985) also analyzes the relative impact of localization and urbanization externalities. Additionally, he distinguishes between different industries. Localization economies are more important for "heavy industries", whereas urbanization economies are more important for "light industries".

Von Hagen and Hammond (1994) test for the existence of localization economies. If they exist "the correlation of employment changes should be stronger among firms of the same local industry than among firms pertaining to different local industries" (p. 7), which they find is indeed the case. Asset sharing and labor market pooling effects are two commonly cited sources of localization externalities. Von Hagen and Hammond find that the former dominates in more mature labor markets and the latter in regionally growing labor markets.

4.2 Estimating Dynamic External Economies of Scale

According to Stewart and Ghani (1992, pp. 127-131) dynamic ExEOS may arise in the form of changing attitudes and motivation, human capital formation or changing knowledge about technologies and markets. Empirical work on dynamic ExEOS

focused mostly on the effects of local knowledge spillovers between firms in a region or in an industry, which is somewhere between the second and the third effect of Stewart and Ghani. These spillovers may account for different growth rates of industries or regions.

The most obvious form of spillovers may exist in R&D. Firms may not be able to internalize all of the returns to their research such that social returns are higher than private returns to R&D. Hence, one branch of the literature examined the existence and the size of these spillovers. Griliches (1979, 1992) surveys this literature and discusses the econometric difficulties related to this topic. He concludes that "many of these studies are flawed and subject to a variety of reservations, but the overall impression remains that R&D spillovers are both prevalent and important" (1992, p. 29).

Jaffe (1986) finds evidence for local R&D spillovers in a sample of 432 US firms. The number of patents per R&D spending are higher for firms that locate in areas with above average R&D spending. He finds that patents would increase by 20 percent if every single firm increases its R&D efforts by 10 percent. However, profits and market value of low R&D firms decrease with high R&D neighbors. Jaffe (1989) studies the effects of university research spending on corporate patents. He finds evidence that geographical proximity increases the number of patents, after controlling for corporate R&D. Bernstein and Nadiri (1988) analyze the effects of inter- and intra-industry R&D spillovers in five US high-tech industries for 1958-1981. They find that

spillovers result from a narrow range of industries and that there are significant differences in the size of the spillovers between industries. These findings were confirmed by an analysis of the social rates of return of R&D, which were found to be higher than the private rates of return.

Jaffe et al. (1993) find the evidence for local knowledge spillovers by looking at US patent citations. They analyze whether patents are more likely to cite old patents that originate in their own region than in another. Controlling for other reasons than technological spillovers, they find that this is the case. They also find that around 40 percent of a patents' citation come from outside the own technological environment, pointing to the importance of cross-fertilization between different research areas. Analyzing the biotechnological industry, Audretsch and Stephan (1996) find that although knowledge spillovers are important, they are less likely to be locally restricted. They conclude that the geographic dimension of spillovers has been overstated in the literature. By contrast, Audretsch and Feldmann (1996) find evidence for the localization of knowledge spillovers within an industry. Industries tend to cluster locally, if proxies for knowledge spillovers such as local university research, R&D intensity and skilled labor are important factor inputs. It turns out that knowledge intensive industries have a greater propensity to cluster their innovative activities than knowledge extensive industries. Branstetter (1996) uses panel data of US and Japanese firms for the years 1983-1989 in 5 industries with above average R&D/sales ratios. He finds that knowledge spillovers are primarily intranational rather than international in

scope. There is only a small effect that Japanese firms benefit from research of American firms, while a positive effect for American firms of Japanese research could not be identified at all. Irwin and Klenow (1994) and Coe and Helpman (1995) come to different conclusions. Irwin and Klenow showed that international borders are no impediment for spillovers in the semiconductor industry. Coe and Helpman show that a country's total factor productivity (TFP) also depends on the R&D stocks of its trading partners. They find that the more open a country is to international trade, the stronger are the effects of foreign R&D on domestic productivity. They derive these finding by exploiting the cointegration relationship between TFP and R&D stocks. Hence, they estimate levels instead of changes of the to variables as most other studies. They show that in large countries the elasticity of TFP with respect to domestic R&D stocks is larger and the elasticity of TFP with respect to foreign R&D stocks is smaller than in small countries. Concluding, one can say that a vast amount of papers shows the existence of spillovers, which are the origin of ExEOS in many dynamic models. Regarding the spatial scope, the evidence is mixed whether these externalities are restricted locally or not.[25]

[25] For further studies on R&D and spillovers see and Acs and Audretsch (1990), Acs et al. (1992, 1994) Feldman (1994) and Bernstein and Nadiri (1989) and those surveyed in Griliches (1992).

4.3 The Empirical Relevance of External Economies of Scale

Sections 4.1 and 4.2 have shown the existence of static and dynamic ExEOS. Similarly to the case of InEOS, one can ask for the specific relevance of ExEOS for explaining economic phenomena. This section presents evidence for the relevance of ExEOS. It should be noted that only for data reasons a large part of the papers surveyed in this section analyze the US and Brazil. Static and dynamic ExEOS play different roles in different subfields of economic theory.

Static ExEOS are important in location theory. As shown, they help to explain urban agglomerations and the clustering of firms of one industry in the same region. These emerge because factors of production realize higher rewards due to static ExEOS. In order to assess the quantitative importance of static ExEOS, several authors examine the relationship of density or distance to a regional center and factor prices.

Sveikauskas et al. (1985) use a Cobb-Douglas production function in which they include skill levels, learning effects, and InEOS. They estimate the effect of travel time to the center of Sao Paulo city on the productivity of newly built manufacturing firms in Sao Paulo State in eight different industries. On average, a doubling of travel time is associated with a Hicks-neutral 15 percent decline in overall productivity. Hansen (1990) uses the same framework to estimate the effect of agglomeration economies on productivity and wages in Sao Paulo. He finds that Hicks-neutral productivity decreases by 0.11 percent per 1 percent increase in distance from the center-city. He also finds a positive impact of InEOS, with size measured by workers per firm. Losses

in firm productivity due to a larger distance from the center of Sao Paulo are almost totally matched by lower wages. On average, firm productivity declines by 8.9 percent and wages decline by 8.7 percent due to a doubling of distance from Sao Paulo City.

Henderson (1994) sets up a model of industry location and estimates its determinants. He uses 1970 data of auto components and agricultural machinery for Brazil and the US. A doubling of distance to a regional market center from the average of 290 km lowers profits by 6 percent. Profits per firm rise with industry scale but peak after a certain size. This is probably due to market size effects because the peak shifts out with a larger urban size. Hanson (1996) confirms this reasoning with Mexican data on regional wages in the clothing industry. Distance to Mexico city as measured by travel time accounts for 41.4 percent of the variance in regional wages.

Evidence on the relationship of productivity and the density of economic activity has been found recently by Ciccone and Hall (1996). They find that spatial density leads to aggregate increasing returns for US states. According to their study labor productivity rises by about 6 percent for a doubling of employment density. By this, more than half of the variation of output per worker can be traced back to locally ExEOS. Above that they find that increasing returns to density describe productivity differences better than increasing returns to size. Kanemoto et al. (1996) estimate aggregate Cobb-Douglas production functions for Japanese metropolitan areas in 1985. They estimate EOS for different city size classes. Possible productivity increases due to a doubling in size are

25 percent for cities between 200,000 and 400,000 residents, 1 percent for cities below 200,000 residents, and 7 percent for cities with more than 400,000 residents.

Table 7 — Empirical Papers Estimating Static ExEOS

Authors	Methods/Data	Results
Nakamura (1985)	Translog production function; data for 2 digit manufacturing industries in Japan.	Localization economies are more important for heavy industries; urbanization economies are more important for light industries.
Sveikauskas et al. (1985)	Cobb-Douglas function, Data for 8 industries in Brazil.	A doubling of travel time to Sao Paulo city reduces productivity by 15 percent.
Henderson (1986)	Cross-sectional data for US and Brazil.	ExEOS are rather localization than urbanization economies. They die out for larger cities.
Hansen (1990)	Cobb-Douglas function, 1980 data for 356 new manufacturing firms in Brazil.	A 1 percent increase in distance from the city center leads to a 0.13 percent decline in Hicks-neutral productivity. This is almost exactly matched by lower wages.
Henderson (1994)	Tests for the determinants of industry location in Brazil and the US for autocomponents and agricultural machinery.	A doubling of distance to a regional market center from an average of 290 km lowers profits by 6 percent.
von Hagen and Hammond (1994)	Analysis of the correlations of employment fluctuations across firms in the same and in different regions by annual employment data for 4 US cities and three two digit industries.	Localization economies exist, labor policy is stronger in expanding markets, asset sharing is more important for mature markets.
Ciccone and Hall (1996)	1988 data on output per worker in US states	A doubling of economic density increases productivity by 6 percent.

Dynamic ExEOS are important for economic growth theory. They may help to explain why growth rates are different between cities, regions or countries. To test for the impact of dynamic ExEOS, most studies focus on the city level. Given the existence of spillovers, one part of the literature tests the impact of dynamic ExEOS on

growth of industries and regions and evaluates the relative importance of MarEOS and JaEOS. See Glaeser et al. (1992), Bostic et al. (1994), Miracky (1995), Henderson et al. (1995) and Henderson (1995). Glaeser et al. (1992) analyze the determinants of city growth between 1956 and 1987 of 170 US cities. They find that industry employment growth rates in individual industries depend positively on the degree of competition in each industry and the shares of other industries in the region. The influence of the share of the own industry is either insignificant or negative. This confirms the theory of Jacobs rather than those of Marshall-Arrow-Romer although the analysis might be biased by the focus on large and mature cities. Therefore, the analysis cannot rule out that intra-industry spillovers are important for industries in early life cycles.[26] This supposition is confirmed by Henderson et al. (1995). They find evidence for MarEOS as well as JaEOS analyzing data for eight manufacturing industries in 1970 and 1987. For more mature capital goods industries MarEOS, but no JaEOS are prevalent. However, new high-tech industries are more likely to locate in diversified cities. This is consistent with the theory on urban specialization and product cyles that more mature industries move to smaller and specialized cities, while new industries need the diversity of a large city. Using a more intensive data set than Glaeser et al., Miracky

[26] See also the paper by Garcia-Mila and McGuire (1993). They analyze the impact of the industrial mix in US states on the states growth rates and their variability for the years 1969-1985. Thereby, they correct state data for national industrial growth rates and variabilities in order to get net growth rates that depend only on the industrial mix and not on common industry trends. They find that net growth rates are greater in states with higher employment concentration in construction, finance, insurance and real state industries.

(1995) confirms the theories of Jacobs in two ways. First, he finds that industry growth is highest in cities where on average other industries have small establishments. He interprets this to reflect "spillovers of knowledge across firms producing young products" (p. 74). Second, he finds that spillovers occur in cities rather than in larger areas such as US states.

This finding is confirmed in a more general approach by Bostic et al. (1994). They estimate that specialization has had a negative impact on productivity growth for a sample of 79 US cities between 1880 and 1890. Urbanization is negatively correlated with capital growth, positively with correlated with labor growth, and uncorrelated with output growth. The most advanced of all these studies is Henderson (1995). While all previously mentioned studies analyze the employment patterns across locations at two points in time, Henderson analyzes panel data on county employment in five US industries from 1979-1990. He argues that initial conditions may have important effects on dynamic externalities, but that these effects may die out after a certain time. Therefore, it is important to analyze the lag structure of the externality variables, instead of analyzing the impact of the initial industry mix over 10, 16 or 30 years. He finds that MarEOS show their largest impact after three to four years and die out after 5 to six years. By contrast, JaEOS seem to persist till the end of the time horizon of the data, which is eight years.

Table 8 — Empirical Papers Estimating Dynamic ExEOS

Authors	Methods/Data	Results
Jaffe (1986)	1973 and 1979 cross-section data of 432 firms from the NBER R&D panel. Data on patents, profits and market value.	R&D productivity rises with the R&D expenditures of technological neighbors.
Bernstein and Nadiri (1988)	Estimation of R&D spillovers in 5 US-high-tech industries, 1958-1981.	Intra- and inter-industry spillovers exist but vary considerably between industries.
Glaeser et al. (1992)	Data on industry growth in170 US cities between 1956-1987.	Local competition and urban variety, but not regional specialization, encourage industry growth.
Garcia-Mila and McGuire (1993)	Annual employment data for US states, 1969-1985.	The industrial mix helps to explain differences in growth rates.
Jaffe et al. (1993)	1975 and 1980 regional US patent data of universities and corporations.	Local spillovers play an important role, but also cross fertilization since 40 percent of patent citations come from outside the same primary patent class.
Bostic et al. (1994)	79 US cities, 1880-1890.	Specialization has a negative impact on city growth.
Henderson (1995)	Panel data of 742 urban county level employment in various US industries for 1977-1990. Analysis of the lag structure.	Localization externalities have their largest impact after 3-4 years, whereas urbanization externalities go back up to 8 years.
Henderson et al. (1995)	8 manufacturing industries in 1970 and 1987.	Evidence for both MarEOS and JaEOS.

Backus et al. (1992) test whether dynamic ExEOS work on the country level such that larger countries grow faster. They find no evidence that per capita GDP growth is influenced by any of their variables intended to measure scale effects. Only, for manufacturing productivity growth, they find a positive correlation with their scale variables. Jones (1995a, 1995b) tests the time series properties of R&D based endogenous growth models. Neither for the US (1995a) nor for other industrialized

countries (1995b) he finds evidence for scale effects. Even a fivefold increase in R&D employment in the US between 1950 and 1987 did not increases countrywide growth rates. Concluding, static ExEOS increase factor rewards, and, hence, contribute to the understanding of the formation of urban agglomerations and industrial clusters. Dynamic ExEOS increase city and regional growth rates. However, they are no countrywide phenomenon and cannot explain different growth rates between countries.

5. Summary

This paper surveys the empirical literature on internal and external EOS. The main point to note is the distinction of different levels of aggregation on which EOS may occur. Furthermore, static and dynamic effects were set apart to disentangle productivity level effects and productivity growth effects. Evidence on the existence of EOS was found on all levels of aggregation. Engineering estimates as well as econometric estimates provide support for the overall existence of static InEOS. However, data and methodological reasons complicate the approaches used to estimating InEOS and invite criticism concerning their results.

Above that, dynamic InEOS or learning effects were found to be significant as well. These effects were most important in skill intensive industries. Despite the robust evidence on the existence of internal economies of scale, it is less clear how they actually matter for explaining economic phenomena like patterns of production and trade between countries.

Evidence on the existence of static ExEOS has been found within industries (LocEOS) as well as within regions (UrbEOS). Both forms of ExEOS are able to explain higher productivity levels in densely populated areas. As a general results, localization economies seem to be more important than urbanization economies. However, they peter out beyond a certain city size. Hence, static ExEOS can be said to add to the explanation of the existence and structure of urban agglomerations.

R&D and technological spillovers are found to be an important source of dynamic ExEOS. By contrast to the findings on static ExEOS, dynamic ExEOS seem to be more important across (JaEOS) than within industries (MarEOS). This result supports the theory of Jane Jacobs (1969, 1984) rather than the theories of Marshall (1920), Arrow (1962) and Romer (1986). While dynamic ExEOS were found to contribute to the explanation of different growth rates of cities and counties, their impact is less clear for larger spatial aggregates. Thus, dynamic ExEOS can be said to be more likely a local or regional phenomenon than a national phenomenon.

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