7 Creative destruction

"The essential point to grasp is that in dealing with capitalism we are dealing with an evolutionary process" [Joseph Schumpeter].

Learning Goals:

- Understand the private incentives to engage in R&D
- Identify the main sources of knowledge excludability in the real world
- Identify the factors that influence the market value of a discovery
- Acknowledge the different market failures involving innovation

7.1 Introduction

The Solow model, by assuming perfect technological diffusion, cannot capture the incentives of economic agents to engage in research and development (R&D): since knowledge is assumed to diffuse instantaneously at no cost, no agent would be able to reap a return on any eventual invention. In the Learning by Doing model, this limitation is circumvented by assuming that technological progress arises as an unintended by-product of investment decisions. In that model, technological change materializes endogenously, though without reward. In this chapter, we open our lenses to analyse the microeconomic incentives for innovation. Research is explicitly modelled as an economic activity, with a payoff. Innovation then arises as the result of purposeful efforts by individual agents to develop new technologies.

In today's world, much competition between firms takes the form of firms trying to develop new and better products or less costly methods of producing existing products. Selfish economic agents would not be willing to devote valuable time and resources to R&D, unless they expected a reward in case of success. In many markets, that reward takes the form of a temporary economic rent enabled by the exclusive nature of the idea. Exclusion can be acquired through different mechanisms, including trade secrets, lead time, and patents. These mechanisms prevent innovations from leaking out instantaneously, allowing innovators to acquire a temporary market power over their inventions and by then to reap a return on the research efforts. The view that technological progress is driven by the prospect of economic rents is on the basis of the so-called Schumpeterian paradigm of economic growth. In light of this theory, entrepreneurs engage in R&D with the aim to obtain profits. The R&D model therefore departs from the frictionless economy with perfect competition, to assume that knowledge does not diffuse instantaneously. This allows innovators to explore a temporary monopoly power.

In this chapter, R&D is modelled as an economic activity, with the aim to obtain profits. Section 7.2 introduces some basic concepts. Section 7.3 describes the basic model, with a final good sector and a sector producing intermediate inputs. Section 7.4 analyses the incentives to innovate, focusing on the case in which innovations consist in the introduction of new products. Section 7.5 addresses the case in which innovations arise in the form of more efficient technologies to produce existing goods. Section 7.6 addresses the ex ante incentives for an entrepreneur to engage in R&D. Section 7.7 describes alternative mechanisms in which real world' firms rely, to preserve ownership on their inventions. Finally, in Section 7.8 we discuss the market failures underlying the finance of valuable R&D, and the role of government in addressing these market failures. Section 7.9 concludes.

7.2 R&D Taxonomy

7.2.1 Basic research versus R&D

Research and Development activities may be categorized in different types: Basic Research, Applied Research, and Development. *Basic research* relates to studies that aim to improve fundamental knowledge for its own sake, in a manner that may be subsequently helpful across a range of activities. Since the knowledge thereby created discoveries is typically released to become publicly available, it generates no economic rents. Hence, most basic research is carried out in universities and non-profit institutions, typically with government support.

Applied research is aimed at generating specific uses for existing knowledge. Private firms are primarily engaged in applied research, with the aim of using knowledge for commercial purposes. In general, inventions result in prototypes not ready for consumer use. The process of further improving the invention and its production process so as to make it marketable is called *development*.

In this chapter, the incentives to R&D are mostly discussed in the context of applied research: that is, with firms gathering from general knowledge ideas that can be mastered and adapted to produce marketable goods with the aim to obtain profits. At the end of the chapter, we tackle the case of basic research, where the supportive role of the government becomes essential.

7.2.2 Horizontal and vertical innovations

In considering the output of R&D, there is a distinction between "horizontal innovations" and "vertical innovations". *Horizontal innovations* are those that expand the range of available goods. For instance, the bicycle, the automobile, the train and the airplane are all horizontal innovations. Although they all address the same basic problem (e.g., transportation), the fact they do not solve this problem exactly in the same manner implies that consumers will tend to use each newly invented product alongside with the previous ones.

Vertical innovations are those that make existing goods or varieties obsolete. For example, the personal computer has displaced the typewriter as a text processing tool. Also more modern automobiles, computers and software tend to displace older vintages of automobiles, computers and software. So when a vertical invention is achieved, consumers tend to replace the old vintages by the new vintages.

7.2.3 Process innovations and product innovations

A different categorization relates to where in the production chain the innovation materializes. Innovations can take the form of firms trying to develop new and better products, or instead less costly methods of producing existing products. Innovations that lead to the introduction of new products are labelled *product innovations*. Innovations that lead to the introduction of less costly methods of producing existing products are labelled *process innovations*.

Both product innovations and process innovations can be achieved either through horizontal innovations or through vertical innovations: for instance, an improvement in operations management in a factory producing shirts (process innovation) can be achieved either by introducing higher-quality versions of existing inputs (for instance, better software -

vertical innovation) or by expanding the pool of intermediate inputs (for instance, inventing a new algorithm to solve a challenge in operations).

7.3 The basic R&D model

In this section we describe the basic framework where the economic incentives to R&D are to be analysed. In this framework, there is a final good sector where an homogeneous good is produced using a range of intermediate inputs, which in turn are produced using labour only. The final good sector operates under perfect competition, while intermediate inputs may be produced under imperfect competition.

7.3.1 A production function for final goods

Suppose that aggregate output (Y) is an homogenous good, assembled with m intermediate inputs, according to the following production function:

$$Y = B\sum_{j=1}^{m} x_j^{1-\beta} \tag{7.1}$$

Each intermediate input x_j is assumed to depreciate fully after use. In light of (7.1), the larger the number of intermediate inputs, m , the higher the final good production. Hence, an expansion in the number of intermediate inputs m can be seen as form of technological progress, that we label *horizontal*. B is a parameter capturing the role of other inputs (e.g, capital, land), the size of the market, and country-specific factors, such as the quality of domestic policies and institutions.

7.3.2 Production function for intermediate goods

We assume that, once invented, intermediate inputs are produced using labour, only. Labour is homogeneous. Let N_j denote the amount of labour used in the production of intermediate good j. The production function of each intermediate input is assumed linear on labour:

$$x_j = \lambda_j N_j \tag{7.2}$$

The parameter λ_j measures the state of technology in the activity of producing the intermediate input j. Increases in λ_j come along with lower production costs, turning older technologies obsolete. Technological improvements leading to increases in parameter λ_j are labelled *vertical innovations*.

The total number of workers engaged in the production of intermediate inputs is N_Y:

$$N_Y = \sum_{j=1}^{m} N_j \qquad (7.3)$$

Since labour is homogeneous, the allocation of workers across different activities shall obey to a condition ruling out arbitrage opportunities, stating the wage rate must be the same.

7.3.3 Two sources of technological change

Although this model can account for heterogeneity in intermediate sectors, in most of our discussion we don't need this. Hence, let's assume that all sectors are alike, employing exactly the same technology and hiring a number of workers equal to the economy' average (alternatively, you can interpret λ as referring to the "average technology")[114]:

$$\lambda_j = \lambda, \ \forall j \qquad (7.4)$$

$$N_j = \frac{N_Y}{m} \qquad (7.5)$$

Using (7.5) and (7.4), in (7.2) and (7.1), total output in the economy becomes:

$$Y = Bm\left(\lambda \frac{N_Y}{m}\right)^{1-\beta} = Bm^{\beta}\left(\lambda N_Y\right)^{1-\beta} \qquad (7.6)$$

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[114] See Appendix 7.1 for the case in which λ_j differs across sectors.

The last term in (7.6) shows the two possible sources of technological change that expand aggregate output in this model: horizontal (process) innovations (increases in *m*): expanding the pool of varieties for use in production; vertical (process) innovations (increases in λ *):* efficiency enhancements along a product line, allowing each variety to be produced at lower cost.

Box 7.1. The division of labour effect

In our model, an increase in the number of varieties *m* causes output to expand via greater availability of intermediate inputs (equation, 7.1). However, an increase in the number of varieties also gives rise to a *dilution effect*, whereby a given number of workers N_Y is divided by a larger number of varieties (equation 7.5) causing production of each variety to decrease (equation 7.2). On balance, equation (7.6) tells us that the net effect of an increase in *m* is positive. Why is this so?

The reason is that intermediate inputs enter in final good production with diminishing returns ($\beta > 0$): when a new intermediate input becomes available, workers are reallocated away from the production of old varieties to start producing a new variety. This reallocation causes the marginal product of existing varieties to increase, and the marginal product of the new variety to decrease, until they are all equalized. In the end, marginal products are higher across all product lines than before the innovation.

This model therefore captures the benefit of splitting production processes into different – and eventually more specialized - sub-tasks allowing workers to become more efficient in each subtask. This mechanism was coined by Adam Smith as “division of labour”.

7.3.4 The trade-off between production and R&D

In the real World, the activity of researching and developing new products consumes valuable resources such as labs, equipment, and researchers, employing resources that could otherwise be employed in other uses. Thus, there is a trade-off between allocating resources to R&D and to goods production. In the context of our model, the deviation of resources away from production to R&D is captured splitting the total labour force in the economy (N) in two groups: those workers engaged in the production of final goods (N_Y) and those workers engaged in R&D ($N - N_Y$). We denote by μ the fraction of the labour force devoted to R&D:

$$N_Y = (1-\mu)N \qquad (7.7)$$

Using (7.7) in (7.4), and dividing by N, one obtains an expression for per capita income:

$$y = \frac{Y}{N} = (1-\mu)^{1-\beta} B\left(\frac{m}{N}\right)^{\beta} \lambda^{1-\beta} \qquad (7.8)$$

Equation (7.8) illustrates the trade-off underlying the allocation of working time to R&D versus production of final goods: if the economy commits a larger share of the labour force to R&D (μ rises), there will be a negative impact on per capita output, because less working time is devoted to production. At the same time, a higher research effort will allow output to expand faster over time, via faster technological change, that may arise either in the form of more intermediate inputs per worker (*m/N*) or in the form of more efficient ways of producing these inputs (λ).

7.4 Market structure and operating profits

To examine the microeconomic incentives to R&D, consider the case of an entrepreneur that invested some time in research and managed to discover a new technology. In this section we focus on the case in which inventions arise in the form of new intermediate inputs available to production (horizontal innovations). The case where innovation take the form of more efficient ways of producing existing product (vertical innovation) is discussed in section 7.5.

7.4.1 Demand for intermediate inputs

We assume that the final good sector operates under perfect competition. There are a large number of identical firms that maximize profits taking the price of each intermediate input p_j as given. Under perfect competition, the total demand for each intermediate input is such that its price p_j equals the marginal product, $\partial Y / \partial x_j$. From (7.1), this gives:

$$p_j = (1-\beta) B x_j^{-\beta} \qquad (7.9)$$

The demand for an intermediate product j is described in Figure 7.1 by the downward sloping curve crossing points M and C.

7.4.2 The case with a horizontal innovation

Consider the case of entrepreneur that discovered a new intermediate input (say *j*). With no question, the fact that a new intermediate input is available constitutes an improvement for the economy as a whole: as explained in Box 7.1, a larger pool of inputs to be used in production allows the economy to take opportunity of the division of labour effect, improving aggregate efficiency. A different question is whether the invention comes along with a gain to the inventor himself. This will depend on the profits obtained in producing (or selling the rights to produce) the new design – *operating profits* - compared to the fixed cost related to R&D.

To analyse the entrepreneur' problem, we refer to Figure 7.1. The downward sloping curve crossing M and C is the demand for the input *j* by the final good sector - equation (7.9). The marginal cost of producing this intermediate input with technology (7.2) is represented in the figure by the horizontal line crossing T and C (it is assumed that the innovator is price-taker in the labour market, so the wage rate *w* is given).

Given the marginal cost and the selling price, the operating profits are defined as:

$$\pi_j = p_j x_j - \frac{w}{\lambda_j} x_j \qquad (7.10)$$

Whether these profits are positive or nil, it depends on the market structure.

First, consider the case were the new technology becomes freely available to all agents in the economy. In that case, the new variety will be produced by a large number of price-takers facing a marginal cost equal to w/λ_j. Profit maximization when the price is given delivers $p_j = w/\lambda_j$ and zero profits for all firms. This case is represented in Figure 7.1 by point C, where, $p_j = w/\lambda_j$. Of course, since in this case the innovator has no profits, he will not be able to recover the (sunk) cost F involved in the previous research activity.

In alternative, consider the case in which the inventor is the only one authorized to produce the new variety, becoming a price-maker. Substituting p_j for (7.9) in (7.10), his problem will be to choose x_j so as to maximize:

$$\pi=\left(1-\beta\right)Bx_j^{1-\beta}-\frac{w}{\lambda_j}x_j\,. \tag{7.11}$$

The solution of the maximization problem is the well-known rule stating that the monopolist' optimal price is a mark-up over the marginal cost:

$$p_j=\frac{1}{1-\beta}\left(\frac{w}{\lambda_j}\right). \tag{7.12}$$

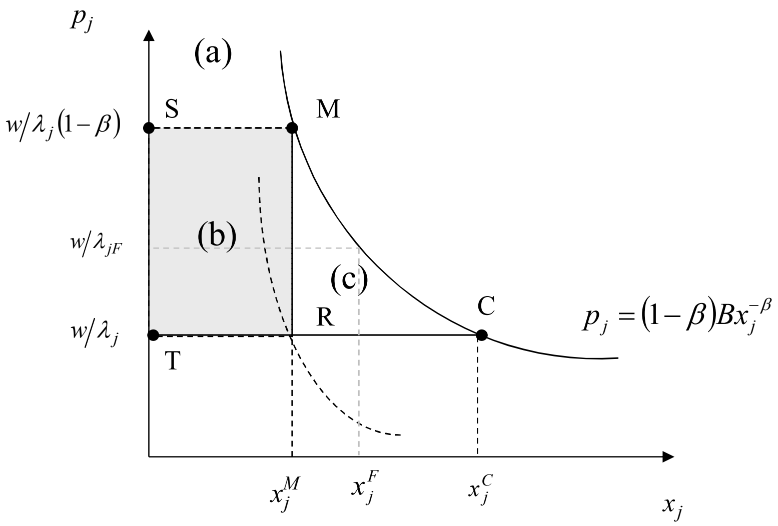
In (7.12), the optimal "mark-up" depends negatively on the demand elasticity $1/\beta$: the lower it is, the higher the mark-up.

Substituting (7.12) in (7.11) one obtains the monopolist *operating* profits:

$$\pi_j=\frac{\beta}{1-\beta}wN_j\,, \tag{7.13}$$

In Figure 7.1, the monopoly case is represented by point M, which correspond to the intersection of marginal costs with marginal revenues - the dashed curve. The shaded area (b) measures the firm' operating profits.

Figure 7.1. Ex-post monopoly profits in the case of an horizontal innovation



Under perfect competition, the price will be equal to the marginal cost (point C). Under monopoly, the price is such that the marginal cost equals marginal revenues (point M), unless a competitive fringe forces the entrepreneur to set the limit price (w/λ_{jF}).

7.4.3 The dilution effect

In the discussion above, we analysed how the discovery of a new product impact on the entrepreneur profits, assuming all else equal. This is the right assumption to analyse the microeconomic decision of an agent that is small in respect to the economy. Collectively, however, technological change impacts on aggregate income, and by then on the wage rate, affecting individual profits.

To see this, let's assume that all *m* sectors are run by incumbents with full monopoly power, as described by equations (7.12)-(7.15), and that all sectors are alike, implying (7.5). Since labour is homogeneous, the wage rate must be such that demand for labour in the production sector equals the supply of labour in the production sector. In that case, it can be shown that the expression for monopoly profit in each sector becomes (see appendix 7.1 for details:

$$\pi_j = \beta(1-\beta)\frac{Y}{m} \qquad (7.18)$$

This equation shows that monopoly profits in each sector decrease in direct proportion with the sector market share (*1/m*): all else equal, when the number of intermediate inputs increases, there is a dilution effect whereby the demand for each input declines, impacting negatively on monopoly rents. Trye, an expanding number of varieties also impacts on the size of the market, Y, but less than proportionally (equation 7.6). Hence, the net effect of continuous horizontal innovations is a continuous erosion in the incumbents' profit. Technological progress arising from the expansion in the number of varieties exerts a negative macroeconomic externality on incumbents[115].

7.4.4 Static efficiency versus dynamic efficiency

The basic microeconomic theory tells us that monopolies are a source of inefficiency. This can be illustrated in terms of figure 7.1, comparing the welfare gains of the innovation under monopoly and under perfect competition.

The welfare gain of the innovation in the case with monopoly is given by the area (a)+(b), corresponding to the efficiency-enhancing effect in production, due to the arrival of a new intermediate input minus the cost of producing it. Under perfect competition, the consumer prices falls to w/λ_j, and the welfare gain of the innovation increases to (a)+(b)+(c), all accruing to consumers. Hence, the monopoly involves a transfer from consumers to the innovating firm (b) and a deadweight loss to the economy as a whole equal to (c).

The other side of the coin is that ex post monopoly profits are necessary to reward the research effort, without which there would be no consumer gain at all. As with many other problems in economics, there is a trade-off here: some excludability is inefficient from the static point of view, but it may provide the incentives for private agents to develop more ideas, which is good for all. This reasoning led one of the pioneers of modern development economics, Joseph A. Schumpeter (1883-1950) to claim that “static” efficiency and “dynamic” efficiency do not necessarily go along

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[115] Using (7.6), equation (7.18) can also be written as $\pi_j = \beta(1-\beta)B\left[\lambda N_Y/m\right]^{1-\beta}$. A feature of many models with monopolistic competition is that the number of varieties *m* is set to increase proportionally to the size of the labour force, N. When this is assumed, the ratio *N/m* remains constant and the dilution effect on profits is eliminated. The model in appendix 7.2 goes along with this avenue.

7.5 Competition through innovation

The section above explored the case in which innovations consisted in the introduction of new varieties. We now turn to the case of technological improvements along existing product lines – that is, increases in λ. When innovations are vertical, incumbents are challenged by the possible entry of new competitors offering exactly the same product. Such competition may either force incumbents to reduce prices, to share the market, or even do abandon the market, in case the new technology is more efficient than the older one.

7.5.1 Limit pricing

A first case of competition along a product line occurs when incumbent monopolists face the threat of market entry by less efficient suppliers of the same product. These less efficient competitors can appear by imitation, knowledge leakages, or through the development of lower quality designs of the same product. Even if these suppliers do not actually enter in the market, they may force the incumbent to set a *limit price*, to prevent entry.

To examine this case, let's return to Figure 7.1. Suppose that the incumbent in the market for j is challenged by a large number of imitators (*competitive fringe*) that cannot exactly replicate the incumbent technology, but are able to produce the same product at some higher cost (lower labour productivity), $\lambda_{jF} < \lambda_j$. In case the imitators' disadvantage is not too large – as illustrated in the figure - then the best the incumbent can do to remain monopolist is to set the price just marginally below w/λ_{jF} (the *limit price*). Setting the limit price, the incumbent is able to undercut its rivals and preserve the monopoly position. However, operating profits, $\pi_{jF} = \left(w/\lambda_{jF} - w/\lambda_j \right) x_j$ will be lower than in the unconstrained case.

In sum, potential competitors may constrain the pricing behaviour of the incumbent, even if they don't actually operate. When this is so, it is the competitive fringe that (indirectly) sets the market price, not the monopolist. Consumers are of course better off under limit pricing: prices are lower than in the full monopoly case, and the quantity supplied (x_j^F) is higher. But the incumbent will get a lower return on his research effort.

7.5.2 The case with a more efficient vertical innovation

A different case occurs when the technology developed by a newcomer is more efficient than the existing one. In that case, the opportunity arises for the newcomer to outprice the previous competitors, driving them out of the market.

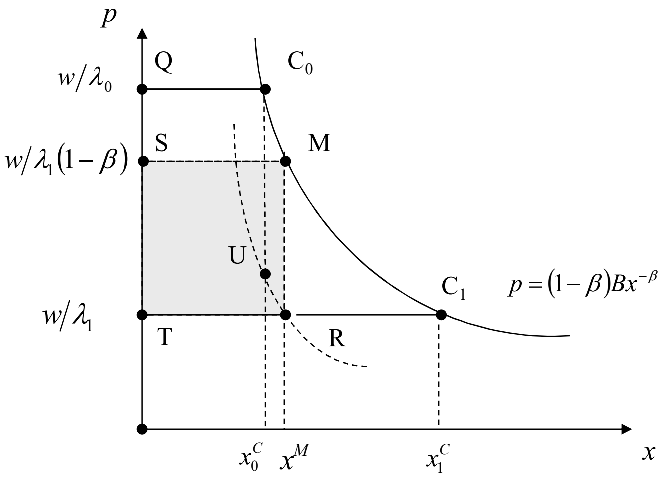
To analyse this case, assume that prior to innovation the market for product j was perfectly competitive: that is, a large number of firms were producing j with a given technology λ_0 (the suffix j is omitted to simplify the notation). In Figure 7.2, the equilibrium prior to the innovation is described by point C_0, where the price is equal to the marginal cost (w/λ_0), profits of each firm in the fringe are zero, and the total demand for this variety is x_0^C. Departing from C_0, suppose that an entrepreneur found a more efficient way of producing the same product. In Figure 7.2, the vertical innovation is described by the fall in the (horizontal) marginal costs curve from w/λ_0 to w/λ_1.

As in the case with the horizontal innovation, the innovation may translate into an effective competitive advantage to the innovating firm or not, depending on the innovator's ability to maintain exclusive control over the technology created: If competitors had immediate access to the new design, the market price would fall to w/λ_1 and the total demand for the good would increase from x_0^C to x_1^C. In that case, there would be no monopoly profits and consequently no reward to the time spent in R&D.

If, in alternative, the innovating firm had exclusive access to the new design, it could charge a price lower than the previous competitive price, driving all competitors out of business and become monopolist in this particular sector. In this case, it will be possible for the firm to generate profits to reward the previous research effort.

A previously competitive firm that beats its competitors through a vertical innovation and achieves a monopolist position in the market is said to have *escaped competition.*

Figure 7.2. Ex-post monopoly profits in the case of a drastic vertical innovation



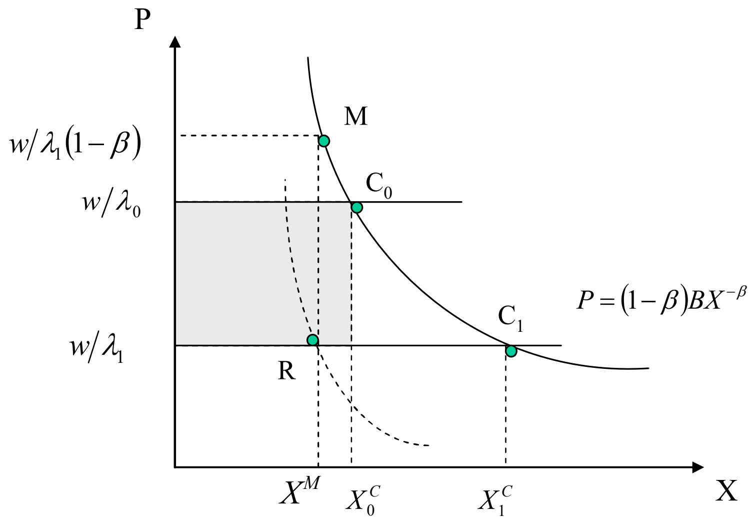
When the vertical innovation is drastic, the innovating firm is able to set the full monopoly price, because the intersection of the marginal cost and marginal revenue in point R implies a price that that is lower than the pre-innovation competitive price.

7.5.3 *Drastic versus non-drastic vertical innovations*

The firm that escapes competition and becomes monopolist does not always set the full monopoly price (7.12). That will be possible only in case the resulting price does not exceed the previous market price. Otherwise, the best the innovator can do is to set a limit price.

These two alternative scenarios are illustrated in figures 7.2 and 7.3. In Figure 7.2, the innovating firm is able to set the full monopoly price, because the intersection of the marginal cost schedule (w/λ_1) with the marginal revenue in point R implies a monopoly price (point M) that is lower than the original competitive price (w/λ_0). This case is known as a *drastic innovation*. The implied operating profits corresponds to the shadow area in the figure.

Figure 7.3. The case with a non-drastic vertical innovation



In the case of a non-drastic innovation, the equality between the new marginal costs curve and marginal revenues (point R) implies a monopoly price (point M) exceeding the competitive price. Hence, the best the innovating firm can do is to set the price just marginally below the competitive price undercutting its rivals and capture the entire market.

Figure 7.3 illustrates the alternative case, of a *non-drastic innovation*. In the figure, the equality between the new marginal costs curve (w/λ_1) and marginal revenues (point R) implies a monopoly price (point M) exceeding the original competitive price (w/λ_0). Hence, the best the innovating firm can do is to set the price just marginally below the previous competitive price (w/λ_0). In doing so, it will be able to undercut its rivals and capture the entire market, pocketing the difference between this price and the new marginal cost, w/λ_1 .

Summing up, a drastic innovation corresponds to a sufficiently large improvement in technology so that the innovator becomes full monopolist. In the case of a non-drastic innovation, previous producers constrain the pricing behaviour of the entrepreneur, even if they don't actually operate[116]. In the case of a drastic innovation. the consumer price falls and quantity increases, so consumers are better off. This contrast to the case of a non-drastic

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[116] Formally, you may verify that the innovation will be drastic if: $\lambda_1/\lambda_0 > 1/(1-\beta)$. Intuitively, when the demand is rigid, the full monopoly price is very high relative to marginal costs and therefore is more likely to exceed the competitive price.

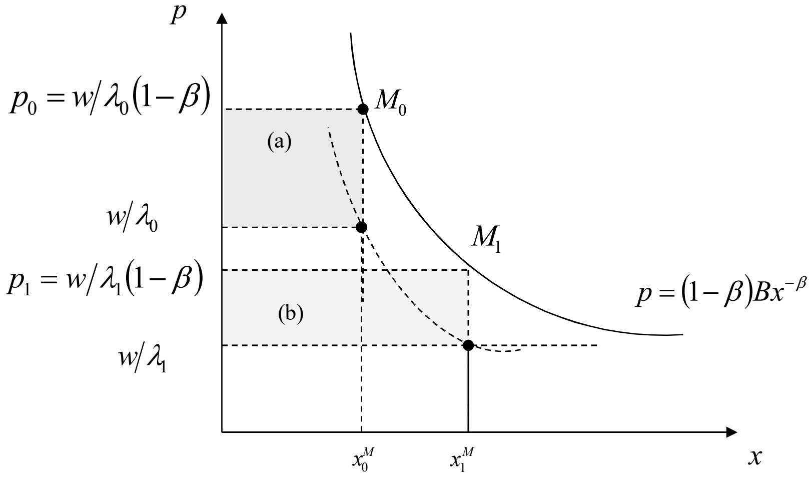
innovation, where quantities remain unchanged and the only source of social gain is the increase in the producer surplus.

7.5.4 Creative destruction

In Figures 7.2 and 7.3 it is assumed that prior to the innovation the market was under perfect competition. In alternative, one may consider the case where the market was run by an incumbent monopolist. In that case, the vertical innovation comes along with the destruction of an existing economic rent.

In figure 7.4, we illustrate this, referring to a drastic innovation. The equilibrium prior to innovation is described by point *M₀*. This equilibrium corresponds to the intersection of the incumbent' marginal costs curve (w/λ_0) with the locus of marginal revenues (the dashed curve), implying a price equal to $p_0 = w/\lambda_0(1-\beta)$ and a total demand equal to x_0^M (the suffix j is omitted to save algebra). The incumbent' operational profits (7.13) corresponds to the area (a).

Figure 7.4. Creative Destruction



The figure describes a case where a vertical innovation is large enough for the newcomer to become full monopolist driving the previous monopolist out the market. Since previous to innovation the market was monopolized, the arrival of the new technology came along with the destruction of existing rents.

Now assume that an entrepreneur invents a new technology allowing marginal costs to fall to w/λ_1 . As represented in the figure, the innovation is drastic because it allows the entrepreneur to set the full monopoly price and still undercut its rival. The new monopoly price falls to $p_1 = w/\lambda_1(1-\beta)$ and production increases from x_0^M to x_1^M. With the innovation, the entrepreneur achieves operational profits equal to area (b), and the old rent (a) is destroyed at the benefit of consumers.

The view that firms bringing new technologies enter in the market destroying existing rents is on the basis of the Schumpeterian paradigm of economic growth[117]. Joseph Schumpeter (1883-1950) theorized that the introduction of new products, new production processes and new forms of industrial organization by innovating firms undermine the marketability and the value of existing designs and production techniques. Innovating firms therefore obtain rents that come along with the destruction of their rivals' rents. The newly generated rents allow inventors to reap a temporary return on their research efforts. But innovation rents do not last forever: sooner or later other firms will come up with new and better designs and production techniques, causing the incumbents' rents to erode.

The process through which technological change leads to the disappearance of old activities and firms, and the reallocation of resources to newer and more promising areas was labelled by Schumpeter as "creative destruction". Along this process, there are winners and losers. Firms that fail do adapt, experiment losses and are forced out of business. Surviving firms are forced to continuously revise their plans and production techniques, in process of permanent adaptation. In light of the Schumpeterian view, creative destruction allows the market economy to incessantly revitalize itself, in a process that resembles the Charles Darwin' theory of natural selection (see Box 7.2).

Box 7.2. The theory of natural selection

In its primitive form, the pea plant evolved a gene that makes its pods explode when peas are ready for germination. This mechanism allows peas to be scattered on the ground,

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[117] Schumpeter, J., 1912. Theorie der Wirtschaftlichen Entwicklung. Leipzig: Dunker & Humblot. Schumpeter, J., 1950. Capitalism, Socialism and Democracy. New York: Harpe.

ensuring the survival of the species. In each generation of pea plants, however, a number of mutants grow by accident lacking this key genetic ingredient: pods of mutant peas fail to pop up. In the wild, mutant peas die entombed in their pods. The natural selection therefore ensures that only the healthy pods pass on their genes.

When the man invented agriculture, the direction of natural selection was changed. Humans were not interested in the primitive version of the pea plant, because it is much more convenient to gather pods with peas enclosed directly from the plant, than to search for peas scattered on the ground, one by one. Thus, once the man became a farmer, it started growing the mutant version that fails to explode. Today, the pea plant we see in our fields is the mutant version, not the primitive. Farmers reversed the direction of natural selection: the formerly successful gene became lethal and the formerly lethal mutant became successful.

This example, described by Jared Diamond in his famous book *Guns, Germs and Steel*[118], illustrate the Darwin's concept of "natural selection": in the nature, each new generation of a species produces a number of mutants. Because in general mutants are not endowed with the same genetic information that their ancestral developed for thousands of years, they are in principle more vulnerable to environmental challenges. The natural processes of differential survival and reproduction does the selection. In critical junctures, however, the mutant "competencies" may turn out to become an advantage instead of a threat: changes in the natural environment may cause a mutant variety to become naturally selected. In these cases, the population undergoes an evolutionary change.

Like living species, economic agents adapt to changes in the economic environment. Agents tend to follow strategies that proved successful in the past. Successful strategies emerge as the outcome of a learning process, in the interaction game between individual competences and the economic environment. Occasionally, agents experiment new strategies. This is innovation. When the new strategy fails, agents retreat to the old strategies. Whenever the new

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[118] Diamond, J., 1998. *Guns, Germs and Steel: a short history of everybody for the last 13,000 years*. Vintage, Surrey, UK.

strategy succeeds, the innovator acquires a competitive advantage. This advantage will render previous strategies obsolete. As time goes by, other agents start copying the more effective strategy, until it becomes dominant. This is Creative Destruction.

7.5.5 Neck-and-neck competition

The discussion so far has stressed the idea that product market competition, by eroding the rents that reward successful innovations too soon, discourage R&D. This idea captures the Schumpeterian argument that less market competition is good for growth. There is however another reasoning pointing in the opposite direction: when incumbents face the threat of their rents being eroded by new entrants, they will have incentive to escape competition by innovating further. When, in contrast, incumbent monopolists are protected with high barriers to entry, they will have little incentives to keep innovating[119].

In this section, we complete the analysis on the relationship between competition and economic growth, considering a form of *dynamic competition*, according to which incumbents, facing the threat of their rents being eroded by competing innovations, try to "escape competition" innovating faster. In light of this reasoning, more competitions is good for R&D[120].

Consider the market of a given sector *j*, where innovations arise as improvements in labour productivity (λ). Instead of assuming that outsiders always undercut incumbents (figures 7.2-7.4), we now account for the possibility of imitators to exactly catch up with the

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[119] Arrow (1962) showed that the monopolist' incentives to innovate are reduced by a "replacement effect", whereby the rents made possible with the new technology are just replacing rents that the monopolist was already capturing under the previous technology [Arrow, K (1962), "Economic Welfare and the Allocation of Resources for Invention", in Universities-National Bureau Committee for Economic Research (ed.) The Rate and Direction of Inventive Activity: Economic and Social Factors, Princeton, NJ: Princeton University Press. pp. 609-626].

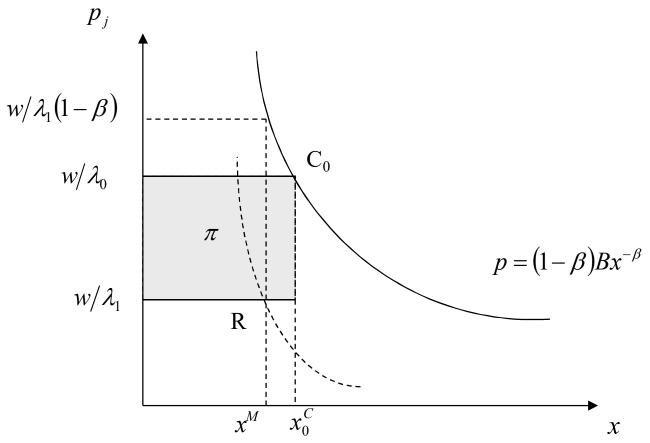
[120] Aghion, P., Harris, C., Howitt, P., Vickers, J., 2001. Competition, imitation and growth with step-by-step innovation. Review of Economic Studies 68, 467-492. Aghion, P., Harris, C., Vickers, J., 1997. Competition and growth with step-by-step innovations: an example. European Economic Review, Papers and Proceedings, 771-782.

frontier technology, forcing the incumbent to *share* profits. At any point in time, there will be *two* possible market structures in the industry: “neck-and-neck”, in which more than one firm compete using the frontier technology; and “unlevel”, in which only one firm holds the frontier technology and supplies the entire market.

Referring to figure 7.5, assume that the market is initially “unlevel”. The incumbent holds technology λ_1 (the “frontier technology”) but its advantage relative to the technology at the fringe (λ_0) is non-drastic. Hence, the best the incumbent can do is to set the price just marginally below w/λ_0, capturing all the market, and pocketing the difference between the limit price and the marginal cost w/λ_1. The incumbent profits are equal to the shaded area in the figure (π). All potential competitors are priced out, so their profits are zero.

Departing from the “unlevel” case, suppose that one entrepreneur from the fringe successfully innovates and joins the frontier technology, λ_1. This means that, from now on, two firms will be operating in this market, competing “neck-and-neck”. The profits earned by each firm will depend on how agressively they will compete with each other: at one extreme, if they engage in open price competition, the equilibrium price will fall to w/λ_1, resulting in zero profits for both; at the other extreme, if they collude, they can hold the price at w/λ_0 and share equally the profits, obtaining $\pi/2$ each (in this case, the newcomer is said to have “stolen” part of the leader business – see Box 7.3).

Figure 7.5. Neck-and-neck competition



Under “neck-and-neck” competition, the monopoly rent (shaded area) is divided by the number of players using the frontier technology. An increase in the number of players at the frontier reduces the incentives for firms in the competitive fringe to innovate and join the frontier

(Schumpeterian effect) but it increases the incentives for firms at the frontier to innovate further and become monopolist of the new technology ("escape competition effect").

If more firms catch up to the frontier, the share of π obtained by each declines further and the collusive solution becomes more difficult to maintain. Thus, for laggard firms, the higher the degree of competition at the frontier, the lower the incentives to catch up technologically and join the incumbents in the neck-and-neck state. This captures the conventional "Schumpeterian effect", according to which increased competition discourages innovation.

For firms already in the neck-and-neck state, however, there will be more incentive to innovate the higher the level of competition at the frontier. The more competition at the front, the lower the firm's profits there, and hence the higher the benefit of escaping competition innovating further. In case a firm at the front manages to discover a superior technology, it will be able to undercut its rivals, becoming monopolist in a new "unlevel state". Through this "escape competition effect", there will is a positive relationship between product market competition and innovation.

In sum, once we account for the possibility of neck-and-neck competition, the relationship between product market competition and incentives to innovate becomes ambiguous: on one hand, the higher the intensity of competition in a given market, the lower the incentive for outsiders to innovate and join that market; on the other hand, the larger the number of firms competing neck-and-neck in a given market, the bigger the incentive for one of these firms to "escape competition" innovating further and achieving a monopolist position. In light of this reasoning, R&D intensity should be higher in "unlevel" industries characterized by low competition (where the Schumpeterian effect dominates), and in "neck-and-neck" industries with high competition (where the "escape competition" dominates), but not much in intermediate states[121].

Box 7.3. The Business Stealing Effect

When an entrepreneur from the fringe successfully joins the leader in neck-and-neck competition, there is a partial deviation of rents from the leader to the newcomer. In this case, the innovator is said to *steal business* from the incumbent. The business stealing effect implies that the rents earned by the imitator correspond to losses by the previous monopolist, without delivering a net gain from the social point of view. On the contrary, the possibility exists for R&D efforts in this case to be welfare reducing.

Referring to figure 7.5, consider again the case of an entrepreneur from the fringe that invests in R&D to imitate the incumbent technology at the frontier , λ_1 . If the two firms collude and share the market equally, then the "business stealing effect" will correspond to half of the shaded area describing the profits. In that case, all the return reaped by the innovating firm will be a mere transfer from the incumbent, and consumers will see no gain at all. As long as the imitation involved a fixed cost, there will be a net loss for the society as a whole, even if the imitator itself had a private gain. From the society point of view, the imitator effort was a mere "stepping on shoes".

7.6 R&D as an investment decision

In the discussion above, we have focused on the operating profits an entrepreneur after the innovation is achieved. The sum of these operating profits along the economic lifetime of the invention correspond to the reward of the innovation effort. In practice, it may happen that operating profits reveal too low - or end up too soon - to cover the initial investment in R&D.

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[121] Aghion et al. (2005), found an inverted U relationship between product market competition and R&D that is supportive of this view [Aghion, P., Bloom, B., Blundell, R., Griffith, R., Howitt, P., 2005. "Competition and Innovation: An inverted-U relationship". Quarterly Journal of Economics 120, 701-728].

Of course, such finding is irrelevant *ex-post*: once incurred, investment in R&D becomes a *sunk cost*. In the production phase, the best the entrepreneur can do is to maximize the eventual operating profits given the market constraints, as explained above (or sell the licence for an equivalent amount), irrespectively of the amount previously invested in R&D.

Yet the *ex-ante* assessment of whether expected returns will be sufficient to pay the fixed costs of R&D is essential to the decision to engage in R&D in the first place. When deciding to devote resources to R&D, the entrepreneur must take into account the fixed costs involved in R&D, the uncertainty regarding the outcome of the research activity, and the expected operating profits during the lifetime of the innovation. In what follows, we focus on the *ex-ante* problem.

7.6.1 The market value of an innovation

The reward of a successful innovation is measured by the discounted sum of operating profits during the lifetime of the innovation. Using a discrete time formulation and ruling out uncertainty, that will be:

$$V=\sum_{t=1}^{T}\frac{\pi_t}{\left(1+r\right)^t} \quad , \qquad (7.19)$$

where *r* refers to the opportunity cost of capital to investors, and *T* refers to the lifetime of economic rents (in case the innovation is patented, T denotes for the length of the patent period). The discounted sum of operating profits (V) can be interpreted as the "market value of the innovation": if the innovator decided to sell today the rights to produce with the new technology, then the higher bid for the license in an auction would be precisely (7.19).

A particular case of (7.19) is when profits are eternal and constant over time. In that case, the perpetuity formula is obtained:

$$\lim_{t\to\infty}V=\sum_{t=1}^{T}\frac{\pi}{\left(1+r\right)^t}=\frac{\pi}{r} \qquad (7.19a)$$

The assumption that profits are constant over time is not the more realistic one. Arguably, profits may erode over time, reflecting the arrival of new products and the *dilution effect*. A simple way to capture this is to assume that monopoly profits decrease at a constant rate *q*, that is $\pi_t = \pi_1 (1-q)^t$. Replacing this in (7.19) and taking the limit as T approaches infinite, the market value of the innovation becomes:

$$V = \frac{\pi_1}{r+q} \qquad (7.19b)$$

In this formulation, the denominator of (7.19b) can be interpreted as the opportunity cost of capital plus a premium to compensate for the time erosion of the cash flow. This formulation is particularly suitable for models with horizontal innovations, where the arrival of new products causes incumbent's profits to decrease over time, without destroying them completely[122].

Equation (7.19b) can also be used to capture the uncertainty regarding the duration of rents under the threat of creative destruction[123]. Assume that the innovator obtains full monopoly power in the first period, enjoying the profits described by (7.13), but is unsure about how long the monopoly power will last for (T in uncertain). More specifically, there is a probability *q* of a superior technology (vertical innovation) being discovered by someone else, turning this technology obsolete. If investors are risk neutral, the value of the license shall obey to a non-arbitrage condition, whereby the expected reward of carrying the license for one period, $\pi_1 - qV$, is equal to the return of investing the same amount of resources at the opportunity cost of capital *r*, that is: $\pi_1 - qV = rV$. Solving for V, the value of the innovation becomes exactly (7.19b). The denominator of (7.19b) shall be interpreted as an "obsolescence-adjusted interest rate", capturing the risk of the current technology being displaced by a superior one: in case of no threat (*q=0),* the value of the license will be given by the perpetuity'

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[122] Romer, P., 1990. "Endogenous technological change". Journal of Political Economy 98, s71-s102.

[123] Aghion, P. and Howitt, P., 1992, "A model of growth through creative destruction". Econometrica, 323-51.

formula, (7.19a); in case $q=1$, then profits only materialize for one period, implying $V=\pi_1/(1+r)$.

7.6.2 The net present value of investment in R&D

The decision regarding investment in R&D involves an *ex ante* assessment on what will be the future cash flows (the value of the innovation, V) compared to the initial research costs. This assessment is complicated by the fact that at the time resources are allocated to a research project, investors do not know for sure whether this investment will deliver a marketable invention.

To model this, suppose that the investment in R&D consists in a fixed cost F incurred in period t=0. Such (certain) investment may deliver an innovation with value V at t=1 with probability b, or nothing with probability $1-b$. In that case, the expected net present value of the research project will be:

$$E[NPV]=bV-F \qquad (7.20)$$

A risk neutral entrepreneur will engage in R&D whenever the expected Net Present Value of the project is positive.

Equations (7.19) and (7.20) summarize the key variables underlying the decision to invest in R&D. These include the fixed cost of R&D (F), the probability of success (b), future operating profits (π), *how long* excludability will last (T), and the discount rate (r). Then you may replace (7.19) by (7.19b), to account for the possibility of profits eroding over time due to horizontal innovations or to be destroyed abruptly due to a vertical innovation.

7.6.3 The break-even value of the innovation

As long as economic agents are free to enter in the research activity, it is natural to assume that competition will drive down the expected NPV in the research sector to zero. In that case, an arbitrage conditions shall hold, stating that the expected value of the research outcome must be equal to the fixed cost in R&D:

$$bV=F \qquad (7.21)$$

In light of (7.21), the larger the required investment in R&D the bigger must be the expected prize to keep investors interested. A higher prize, in turn, requires a larger market, a lower elasticity of demand (β), or a longer monopoly lifetime (T).

This reasoning suggests that the nature of R&D in each industry determines the market structure: in an industry where R&D costs are high and the probability of innovating is low, innovations will only spring if the market is sufficiently protected, with fewer firms and limited competition, to guarantee that profits are large and last for long. This helps explain the high concentration and the high patent-dependence in industries like the pharmaceutical, where research is very specific and costly, and the risk of failure is high. By contrast, the computer-games industry, where new games may be developed with relatively low investment, exhibits a much more open and competitive structure.

7.6.4 The equilibrium level of R&D (partial equilibrium)

Moving one step further, one may use the model to find out the equilibrium level of R&D. In this section, we sketch a partial equilibrium solution, focusing on vertical innovations (see appendix 7.2 for the general equilibrium solution). The key feature of models with vertical innovations is that each innovation is fated to become obsolete at a given point in the future, when a superior technology is discovered by a competitor. Thus, when choosing its research effort, the entrepreneur must balance the potential gain of acquiring market power for some time against the cost of seeing profits disappearing because of the arrival of a superior technology. In this model, individual researchers are discouraged by the efforts of other researchers.

In equation (7.19b) the threat of a superior technology being discovered is captured by the probability q. Arguably, this variable shall depend on the amount of time dedicated to R&D in the same industry. As we already know, whether the relationship between R&D effort and innovation outcome is linear, quadratic, or something else, has no clear answer. In the following, we follow a very simple specification:

$$q = b\mu \qquad (7.22)$$

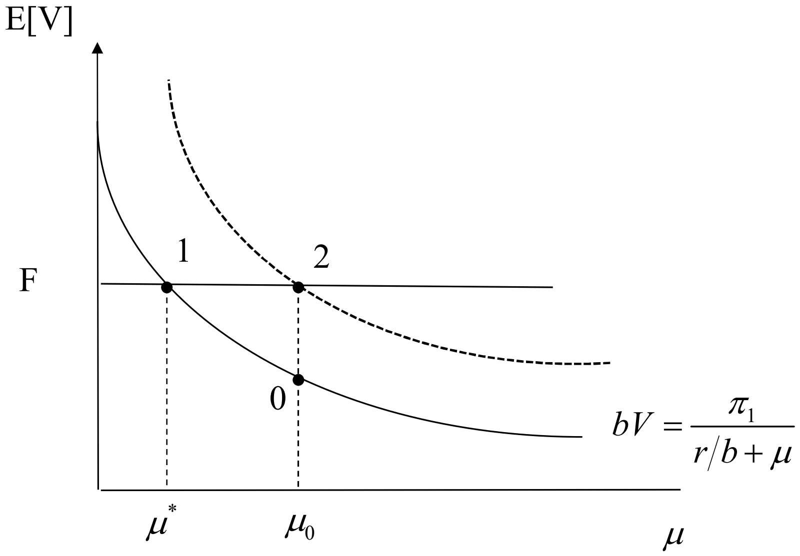
This equation states that the probability of a technology to be displaced by a competing innovation depends on the research intensity in that sector, μ, times the probability of success, *b*. Replacing (7.22) in (7.19b), and then in (7.21), the equilibrium level of R&D in that sector must be such that:

$$b\left[\frac{\pi_1}{r+b\mu}\right]=F \qquad (7.23)$$

The equilibrium level of R&D is illustrated in Figure 7.6. The figure displays the two sides of (7.23) as a function of research intensity. The left-hand side is the expected benefit of R&D: it is a negative function of μ due to the "creative destruction effect": the greater the R&D intensity in the sector, the more likely a competing innovation will destroy one' rents. At the intercept, $\mu=0$, the expected benefit of R&D is the perpetuity formula (7.19a) adjusted for the probability of success. The right-hand side of (7.23) is the fixed cost.

To see how the equilibrium is reached, assume that initially the research intensity is $\mu=\mu_0$ in Figure 7.6. Point 0 is not an equilibrium because the expected benefit of R&D is less than the fixed cost of R&D, implying a negative expected NPV. Thus, workers in that industry will reallocate time away from research towards production. As the research intensity in the industry decreases, the likelihood of a successful innovations being outpriced declines, implying a higher value of a successful innovation (movement along the curve to point 1). In equilibrium (μ^*) the expected benefit of the research activity bF must be equal to the fixed cost, F.

Figure 7.6. Equilibrium intensity of R&D (partial equilibrium)



The figure displays the expected value of R&D in a given sector as a negative function of the research intensity in that sector, reflecting the creative destruction effect. Free entry in research activity implies that, at the margin, the expected benefit of engaging in R&D must equal the fixed R&D cost, F. The curve shifts upwards when operating profits increase. All else equal, this will cause the equilibrium research intensity to increase.

In light of this model, one can analyse the implications of an increase in the value of a successful innovation. That could reflect, for instance, an enlargement in the extent of the market due to openness to international trade: for any given F characterizing an industry, a larger market size (B) will imply higher operating profits, and hence a shorter payback period[124]. In terms of figure 7.6, the curve describing the value of a successful innovation shifts to the right, increasing the expected return of R&D. As long as there is free entry in the research activity, the enlargement of the market will come along with a higher research intensity, and thereby with a faster rate of technological progress: innovators will break even faster because the market is larger and profits are larger, but rents will also be destroyed faster, at the benefit of the consumer. There will be more creative destruction and faster economic growth.

Consider now the impact of an increase in the productivity of R&D, as captured by parameter *b*. Such a change could reflect an improvement in the organization of the R&D sector that turned the research efforts more successful. In equation (7.23) an increase in *b* has two effects: on one hand, it improves the probability of innovation; on the other hand, it increases the likelihood of creative destruction. It is easy to check that the former effect turns out to dominate, so when *b* increases, there will be a higher research intensity and a faster pace of technological progress.

In figure 7.6, the equilibrium is an interior solution. However, this is not a general case: the model does not necessarily imply that the equilibrium level of R&D in any given sector is positive: in case $b\pi_1/r<F$), the two curves will fail to cross each other and the equilibrium level of R&D will be $\mu=0$. That will be the case, for instance, of pieces of knowledge that

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[124] There is a famous quote by Matthew Boulton, a XVIII century British manufacturer and partner of the inventor of the steam engine James Watt, saying: “It is not worth my while to manufacture your engine for three countries only, but I find it very well worth my while to make it for all the world”.

are impossible to hide or to make excludable, implying $\pi_1 = 0$. In these circumstances, the market mechanism will fail to deliver any innovation in the sector.

Also note that the curve describing the expected benefit of R&D refers to *private returns*. It tells us nothing in respect to the *social value* of an entrepreneur to engage in R&D. In any given sector, the social value of the innovation can exceed or fall short the market value, depending on the consumer surplus and on a range of external effects, that can be positive or negative. This means that the research intensity under laissez faire can deviate significantly from the social optimum, giving scope for government intervention.

7.7 Making knowledge excludable

7.7.1 Excludability sources

The discussion above illustrates the key role of excludability in providing market incentives for R&D. Technology is non-rival, but economic rents are rival. When competitors have instantaneous access to the knowledge created and the right to use the new technology, the innovating firm will not be able to raise the required operational profits to reward its initial research effort. In that case, entrepreneurs will prefer to free ride on the other's research efforts, and henceforth there will be no R&D at all. When, in alternative, any mechanism prevents other firms from using the new design - at least during a certain period of time - then the innovating firm will be able to raise operational profits to reward its R&D effort. The less the technology diffuses, the higher the net present value, and the higher the incentives to R&D.

In the real world, there are different mechanisms in which entrepreneurs can rely, to secure some of the gains of their inventions, before knowledge leaks out completely to competitors[125].

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[125] This discussion presumes that the technology created is useful for competitors: if the invention was so specific that it only served the innovating firm, its diffusion would not be a problem.

The first and most obvious mechanism of knowledge excludability is the *trade secret*. By not disclosing the details of an invention, its owner may manage to keep its competitors away from business. This has been the case, for instance, of the famous formula of Coca-Cola, for more than one hundred years. In alternative, the innovator may devote specific efforts to further design the product so as to make very hard for competitors to replicate it. An example of this is encrypting CDs to prevent unauthorized copies.

A problem in many innovative industries is that key ideas are embodied in workers hired and trained by the firm. Thus, there is an obvious risk of workers leaving the innovating firm to join rival firms or to start a competing business independently. In order to avoid this, firms may design compensation schemes that give key employees an incentive to stay together (for instance, by sharing profits). In addition, they can introduce non-disclosure and no-compete clauses in employment contracts. In some cases, fellow firms working in a given location set agreements limiting the exchange of skilled workers between them[126].

Not all inventions, however, are suitable to be protected by trade secrets, encryption, or contract clauses in labour contracts: some ideas are so simple that are very easy to replicate (think, for instance, in the wheel or the "post-it"). In general, the passage of time makes even complex ideas very difficult to hide.

In many industries, the most relevant source of excludability is simply *lead-time*. Knowledge leaks only gradually. So in many industries the problem of competitors free-riding on ones' ideas is circumvented by achieving a faster rate of technological change: innovating firms try to keep the lead continuously developing new sources of differentiation against their competitors. The time length that competing firms take to assimilate new ideas and incorporate them into their own business provides the innovating firm with a first-mover-advantage.

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[126] Whether this is socially good or bad is a different question. For instance, it has been argued that the weak enforcement of non-compete covenants in California may have contributed to the success of Silicon Valley [Gilson, R., 1999. The legals infrastructure of high technology industrial districts: Silicon Valley, Rout 128, and convenants not to compete. New York University Law Review 74, 575-629].

Other advantages for first movers include the time to build up customer loyalty, reputation, and the benefits of experience. Many industries (notably, shipbuilding, aircraft manufacturing, semiconductors) are characterized by a steep learning curve, whereby accumulated experience gives incumbents a significant cost advantage over competitors. This cost advantage does not leak out instantaneously.

Whenever the mechanisms above are not enough to provide the required protection for socially valuable inventions, inventors still have the option to buy legal protection, registering their property rights.

7.7.2 Patents, copyrights and trade marks

Patents are a legal mechanism that establishes private claims on intellectual property rights, permitting innovators to restrict unauthorized use of their ideas. To buy a patent, an inventor must demonstrate that the invention is novel and non-obvious.

A patent grants the inventor exclusive right to its discovery for a definite time length (20 years in Europe and in the US; from 14 to 15 years in the UK). During this period, no producer can use the invention without permission of the patent holder. Patent holders may however license (permit) others to use their invention in exchange for a payment called *royalty*. When the patent expires, other firms are allowed to enter the industry (note that this will not happen with a well maintained trade secret).

When applying for a patent, the inventor must disclose the details of its invention. The knowledge revealed is protected in the sense that only its owner can use it to produce the patented output. Yet the *information* in the patent (the technical details of the invention) can be used freely by other firms, to improve their own research projects. New inventions that do not compete directly with the patented output, even when built on the patent information, are in general considered legal.

An instrument related to patents is copyrights. Copyrights apply to art-works and works of authorship when these are attached to a tangible medium, such as a book or a CD. This contrasts to patents, which apply to products, processes, designs and substances. An important distinction between patents and copyrights is that the later protects the particular expression of an idea, whereas patents protect any tangible embodiment of the idea itself. Therefore, patents allow greater exclusivity than copyrights. In compensation, the society sets copyright terms longer than patents (in the United States copyrights to business last 75 years and copyrights to individuals last for life plus 50 years).

A third category of legal protection of intellectual property are trademarks. The possibility of registering a trade mark encourages firms to develop customer loyalty and reputation. Unlike copyrights and patents, trademarks last forever.

Although legally distinct, patents, copyrights and trademarks can all be viewed as serving the same purpose: they all provide mechanisms of intellectual property protection, preventing others from using an existing idea. The aim is to allow innovators to reap a return on their research efforts.

7.7.3 The economics of patents

The enforcement of legal monopolies by a patent system is not free of controversy. Under monopoly, the firm produces too little and charges too high, imposing a loss on consumers, relative to the perfect competition case (see Box 7.1). In the case of knowledge, a further reasoning applies: since the social cost of allowing more users to share any given idea is zero, does it make sense to exclude other people from using that idea? The problem is that, in many markets, valuable ideas would not emerge at all if there were no legal protection of property rights.

The regulation of property rights has therefore the difficult task of striking a reasonable balance between the static cost of creating legally enforced monopolies with the dynamic gain of providing adequate incentives for researchers. In that problem, there are two key dimensions. The first is the *patent length*: for how long should the patent apply? The second is the *breath* of patent protection: to what range of products should the patent apply?

The optimal length of the patent shall obey to a balance between the need to provide adequate ex ante incentives to researchers and the benefits that will accrue to consumers once the patent expires. The longer the duration of the patent (T), the more time the innovator earns monopoly profits (area *b* in Figure 7.1), and hence the greater will be the incentive to engage in costly R&D (in figure 7.6, the curve describing the value of a successful innovation shifts to the right). However, a long patent length also implies a long lasting monopoly power, which comes along with a static deadweight loss (area c in Figure 7.1). If the life of the patent is too short, the innovating firm may not be able to generate enough profits to reward the research effort; if the life of the patent is too long, there are more incentives to innovate, but consumers will have to wait too long for open competition. The 20 year patent period is intended to strike a balance between static efficiency and the long run objective of stimulating research and innovation.

A similar trade-off applies to the *breath* of patent protection. If an inventor comes up with a product that is similar to one already patented, shall a patent be given to the new variant? If yes, the first inventor will reap less of the returns of her invention. Excessive coverage, on the other hand, will limit competition through innovation in the neighbourhood of the protected idea: other firms will see their returns to further developing the idea squeezed by the royalties they must pay to the original inventor. The optimal choice involves a balance between the need to stimulate R&D and competition through innovation.

In practice, the breath of patent protection is a matter of dispute in the patent office, with later entrants claiming the right to introduce slightly different innovations or new applications of the original idea without paying the royalties. Because litigation results are not always as desired by established firms, the later often protect the invention against other firms "inventing around", by establishing property rights on related ideas, even if never used ("sleeping patents").

Some authors argue that the optimal patent breath and the optimal patent length are not independent. For instance, it has been argued that, because imitators can often get around the patent protection, engaging in a socially costly free ride, and because the incentives to do so increase with the patent length (if the patent duration is short, imitators will find cheaper to wait for the patent to expire), a "short and fat" patent system may be preferable to a "long and thin one". In principle, a short and fat system will come along with faster creative destruction. This optimal patent breath and length remains a controversial topic[127].

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[127] Gallini, N., 1992. Patent policy and the costly imitation. Rand Journal of Economics 23, 52-63. Denicolò, V., 1996. Patent races and optimal patent breath and length. Journal of industrial economics 44, March, 249-65.

7.7.4 The case against patents

Many historians have emphasized the role of institutions governing intellectual property rights as a main driver of economic growth. According to this view, the Industrial Revolution was only possible after governments established a proper regulation and enforced property rights, granting inventors with the necessary ex ante incentives to stimulate research and development[128].

Other authors have argued that the monopoly distortions imposed by the patent and copyright systems are too costly for what they achieve, and they should be severely restricted or even eliminating them altogether[129]. Along this view, it has been claimed that purely private excludability mechanisms, such as first-mover-advantages, lead time, secrecy and imitation delays provide enough protection for innovation and deliver a better allocation of resources than patent and copyright systems. For instance, at the first sight, a patent looks like more efficient than a trade secret, because when the inventor buys the patent, he must reveal the "secret", allowing other inventors to build on it for other uses. Moreover, consumers will have the opportunity to enjoy the benefits of the innovation when the patent expires. However, inventors only buy patent protection when they believe it will be impossible to keep the trade secret for longer than the patent length. Thus, secrets that without patent would be doomed to leak after a short period of time will, with the patent, be maintained for 20 years.

A mechanism that helps reduce the inefficiencies generated by patent protection is licensing: patent holders can permit others to use their invention in exchange for a fee called

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[128] Douglas North (1981), P. 164: "The failure to develop systematic property rights in innovation up until fairly modern times was a major source of the slow pace of technological change" [North, D. 1981. Structure and Change in Economic History. New York: Norton Other]. See also Landes, D., 1998. The Wealth and poverty of Nations. Abacus. Mokyr, J., 2002. The gifts of Athena: historical origins of the knowledge economy. Princeton university press, Princeton.

[129] Merges, R., Nelson, R., 1994. On limiting or encouraging rivalry in technological progress: the effect of patent-scope decisions]. Journal of Economic Behaviour and Organization 25, 1-24. Boldrin, M. and Levine, D., 2002, "The case against intellectual property. The American Economic Review (Papers and Proceedings) 92, 209-212. Kremer, M. 1998. "Patent buyouts: a mechanism for encouraging innovation". Quarterly Journal of Economics, 1998, pp. 1137-1167, November.

royalty. Licensing is welfare enhancing for two motives: on one hand, it prevents competitive innovation and imitation efforts, which are socially costly. On the other hand, because knowledge is non-rival, sharing it, even at a positive cost, is socially better than not to share it at all. Furthermore, from the innovating firm point of view, licensing allows the idea to be used in markets in which the inventor might not have competitive advantage (for instance, in a foreign country). In the real world, licensing is a primary way of transferring know-how across country borders.

In practice, patents are not equally necessary across industries. While some inventions only become available with an enforced patent system, many others become available just as quickly without a patent system. In other words, some inventions are "patent dependent" and others are not. In many industries, sufficient economic incentives for invention and innovation result from secrecy, and first-mover advantages (see Box 7.4). In these cases, the patent system is inefficient, in the sense that the same innovation could be obtained without the cost of granting monopoly power. In the case of medicines, where patents are important, it has been argued that the government (tax payers) should purchase critical innovations and release them to the public, so as to turn critical drugs affordable and to save lives. This would eliminate the ex-post distortion and help without distorting the incentives for firms to engage in R&D in the first place.

Box 7.4 How effective are patents?

Table 7.1 presents the results of a 1987 famous study, that surveyed 650 R&D managers representing 130 lines of business. The executives were asked to rate the effectiveness of patents as well as of other mechanisms, in protecting their competitive advantages, on a scale from 1 (”not at all effective") to 7 ("very effective"). As shown in the table, patent protection was considered the least effective method of protection in the case of process innovations, and te second less effective in product innovations. At the industry level, the authors found that only in pharmaceuticals– and for the particular case of product innovations - did the majority of the respondents rate patents as strictly more effective than other means of appropriation.

Table 7.1. Effectiveness of alternative means of protecting innovations

Effectiveness of alternative means of protecting advantages of new or improved processes and products

Method of Appropriation	Sample means	
	Processes	Produtcs
Patents to prevent duplication	3,52	4,33
Patents to secure royalty income	3,31	3,75
Secrecy	4,31	3,57
Lead time	5,11	5,41
Moving quickly dow n the learrning curve	5,02	5,09
Sales or services effort	4,55	5,59

Note: Range: 1= not at all effective; 7= very effective. Source: Levin, R., Klevorick, A., Nelson, R., Winter, S., 1987 "Appropriating the returns from industrial research and development. Brooking Papers on Economic Activity 3, 783-820.

These surprising results were confirmed by other authors. For instance, authors analysis a survey on 1478 R&D labs in the U.S manufacturing sector found that in most industries patents were the least emphasized mechanism of protection[130]. In the pharmaceutical industry, however, patents were considered an effective protection mechanism for more than 50% of all product innovations. In the case of chemicals, the authors also indicate an important role of patents in *patent blocking*, that is, in deterring the arrival of patents of close substitutes by rivals.

7.8 Financing research and development

7.8.1 Financing constraints

A problem with the research activity is that sometimes it is hard to rise finance. There are many reasons for this. First, most research projects may fail: either because nothing is discovered, because the discovery is beaten in the last minute by a competing firm in the patent

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[130] Cohen, W., Nelson, R, Walsh, J., 2000. Protecting Their Intellectual Assets: Appropriability Conditions and Why U.S. Manufacturing Firms Patent (or Not), NBER Working Paper 7552.

office, or simply because ex post returns are insufficient to cover the initial loan. For all these reasons, the likelihood of involuntary default is non-negligible. Second, the asymmetric information problem that affects financial transactions in general is more pervasive in the case of R&D projects: either because of the technical complexity of the project or simply because researchers do not want to disclose the technical details, investors do not in general fully understand what is envisaged by the researcher. This rises a typical problem of moral hazard: because it is difficult to monitor the true effort and the quality offered by the researchers, there is ample scope for low levels of commitment and to the hiding of relevant aspects of new ideas in the event of success. Third, R&D projects do not in general provide valuable collaterals: in the case of a mortgage loan, if the borrower defaults, the bank can seize the real asset. In contrast, when the bank lends for R&D and the research project fails, the bank may end up with nothing.

This means that, even when the expected NPV is positive, valuable research projects may fail to be implemented, due to lack of finance. Arguably, established firms can raise capital for new R&D out of their profits, or posting third assets, such as real estate, as collateral[131]. But for new entrants, especially small firms, lack of financing may constitute a significant barrier to entry. In the real world, many firms face difficulties in raising capital to finance their R&D projects.

A market-based mechanism that was developed to address this problem is *venture capital*. Specialized financial institutions such as investment banks may invest in promising R&D projects or in start-up companies, in exchange for an ownership stake in the project. Since this comes along with the right to assign a manager in the firm, venture capital not only ensures financing, but also quality management overcoming the problem of moral-hazard that plagues

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[131] Along this reasoning, Schumpeter contended that large firms have an advantage because they have more resources to invest. Schumpeter also conjectured that large firms are more likely to engage in R&D because they can explore economies of scale and spread risks across multiple research projects.

conventional loan contracts. Still, venture capital rarely meets the existing needs, especially at the smaller end of the market, where transaction costs are high relative to expected returns.

Along the last decades, new sources of funding have emerged in industrial countries, including online marketplaces that offer innovative financial services, such as equity crowdfunding, peer to peer lending, and mini-bonds, small alternative markets and fintech. In general, as new and more complex securities become available, risk-spreading opportunities for investors increase, with the consequence of increasing the availability of funds to risky projects. However, most emerging, and low-income economies remain financially underdeveloped. As banks remain dominant as sources of finance, entrepreneurs tend to choose inferior but safer strategies, such as imitating existing technologies rather than inventing new ones[132].

Box 7.5. Positive externalities on R&D

Along this chapter we have stressed the role of knowledge excludability in providing market incentives to innovate. A different question is whether knowledge excludability – even when fully achieved– will provide the enough incentives for entrepreneurs to engage in the socially optimal R&D. Although innovations come along with positive and negative externalities, in general the social benefits of innovations are bigger than the private benefits. Two main effects contribute to this.

The first is the (static) “appropriability effect”, that can be explained with reference to Figure 7.1. Unless the monopolist can discriminate prices, the monopoly profit (area b) will fall short the social benefit of the invention (area $a+b$), that also includes the consumer surplus (a)[133]. The appropriability effect implies that a socially beneficial innovation may fail to occur,

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[132] Acemoglu, D., Zilibotti, F., 1997. Was Prometheus unbounded by chance? Risk, diversification and growth. Journal of Political Economy 105, 710-751

[133] In the case of a drastic vertical innovation, the increase in consumer surplus also implies a social gain larger than the private gain. In Figure 7.2, we see that ex post profits are given by the area [SMTR] while the increase in social welfare is the area [QC$_0$MRT].

even if perfectly excludable. In terms of Figure 7.1, this will be the case when the cost of the innovation (annualized) lies between the areas (b) and (a)+(b). The second is the (dynamic) "standing on shoulders effect": due to the cumulative nature of knowledge, innovations stimulate further innovations.

The appropriability effect and the standing on shoulders effect imply that innovating firms will not, in general, appropriate all the benefits of their innovations to the society. Thus, in a decentralized economy, they will not innovate as fast as it would be socially desirable. In terms of figure 7.6, the curve describing the social value of the innovation lies above the curve describing the market value of the innovation (like de dashed and the solid curves).

7.8.2 Subsidies to private R&D

Wherever ex post monopoly rents that the innovator can capture fall short the social welfare created by the invention, private firms will not innovate as fast as it would be socially desirable. In that case, there is scope for the government to support innovation.

A common policy instrument is the subsidy. In terms of figure 7.6, a government subsidy to R&D will cause the horizontal schedule describing the fixed cost to move downwards, rising the incentive to R&D. Government subsidies can be attributed either to specific innovation projects, to particular innovation activities or more generally to research projects in particular industries.

Some authors argue that government subsidies should target differently different industries, on the ground that they are more needed in more competitive environments (because there are no profits) and were potential for technological spillovers are larger. Designing different subsidies to different industries involves however, a large level of discretion. In a world where governments face important information failures, a question of level-playing-field arises: firms or sectors benefiting from a government subsidy may obtain an undesirable competitive advantage against their competitors at the expense of the taxpayers. For this reason, international agreements and some domestic competition laws (such as in the U.S. and in the E.U.) have been limiting narrowly focused subsidies and state-aids to particular firms. By contrast, broad-based subsidisation mechanisms to particular activities, such as R&D tax credits, because they do not depend on government selection of particular projects or industries, are inherently less distortionary and hence more tolerated by the domestic competition laws and international trade agreements.

7.8.3 Government funded R&D

So far, we have analysed mechanisms of government support to R&D that are market based. By establishing and enforcing a system of property rights and by subsidizing innovative activities, government may help firms appropriate more of the social benefits of their innovations, inducing R&D efforts more aligned with the social interest.

Not all research, however, is driven by market concerns. For example, advances in *basic sciences*, such as geography, economics, mathematics and physics cannot be patented. Hence, there are no rents to extract. And yet, because of the large externalities involved, advances in basic science are of great importance for the progress of human kind.

On the other hand, even when particular types of knowledge are suitable for exclusion, it may be socially preferable to make them freely available. Remember that, because knowledge is non-rival, the social cost of having more agents sharing the same idea is zero. Given the cumulative nature of knowledge – i.e, new discoveries build on old discoveries – there is a good case to let relevant pieces of knowledge to become freely available, even when the alternative of patenting is possible.

As with public goods in general, governments may have a role in supporting directly the creation of knowledge. One possibility is to reward with prizes and research grants the creation of knowledge that becomes public property. For instance, academic and government scientists do not work with the primary objective of profit-maximisation. Their main incentive is to disclose the product of their research in order to receive rewards. This kind of support is known as "patronage"[134].

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[134] David, P., 1992. Knowledge, property, and the system dynamics of technological change. Proceedings of the World Bank Annual Conference on Development Economics, 215-248.

Governments may also promote research and development through “procurement”. In this case, a public body contracts out in advance for a specific piece of research to be undertaken. With this mechanism, the government absorbs some or all the risks that the private firm would otherwise have to address. Depending on the interests of the government, the findings of the research undertaken under procurement may become publically available or not. In the case of military research and big space programmes, such as those managed by NASA in the USA, disclosure is not in general allowed.

Government funded R&D accounts for between one-third of total R&D expenditures in US and one half Europe[135].

7.9 Key ideas of chapter 7

- Private agents dedicate valuable resources to the development of new technologies because they expect to be rewarded in case of successful innovation. In the market, the reward of successful R&D depend on the possibility of making the new technology marketable and excludable.
- Monopoly rents made possible by R&D depend on the size of the market, on how long the technological advantage will last, and on the emergence of competing innovations.
- When entrepreneurs achieve a successful innovation, they often destroy rents of non-innovating firms. This competitive nature of R&D is labelled Creative Destruction and resembles the Darwin theory of natural selection.
- The fact that the reward to innovation comes in the form of monopoly profits does not necessarily imply that less competition is good for innovation. True, a market with low competition will be more attractive for newcomers, so through this “Schumpeterian effect”, less competition is good for innovation. However, high product market competition at the frontier also creates the incentives for firms in that market to innovate as a form of “escape competition”.
- Investments in R&D involve certain costs to obtain uncertain outcome. The larger the required investment adjusted for the probability of success, the less competitive the industry must be for R&D investment to break even.

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[135] Keely, L, and Quah, D., 1998. “Technology and Growth”, Centre for Economic Performance Discussion Paper Nº 391, London School of Economics, May.

- A technology can be made exclusive by market mechanisms, such as secrecy, lead-time, and customer loyalty. When these are not enough, innovators may secure property rights through legal mechanisms, such as patents, copyrights and trademarks. In practice, patents are likely to be an important source of excludability in few industries, such as chemicals and pharmaceuticals. Some authors contend that the dynamic gains achieved with the patent system are not enough to offset the static costs.
- The market mechanism may deliver too little R&D. Even if private incentives exist, financial constraints may prevent a talented researcher from engaging in productive research. Financial development is a key condition for innovation.
- Private researchers do not in general fully appropriate the social benefits of their inventions, even when property rights are fully enforced. This means that the government may have a role in stimulating the research activity through subsidies and research grants.

Appendix 7.1. The dilution effect and the crowding out effect

In this appendix, we extend the model in the main section to the case in which labour productivity λ differs differs across sectors. We stick to the assumption that all sectors are monopolized.

In each sector j, the optimal production is obtained substituting (7.12) in (7.9). Using (7.2), the corresponding labour demand is:

$$N_j = \lambda_j^{\frac{1-\beta}{\beta}} \left[\frac{B(1-\beta)^2}{w} \right]^{\frac{1}{\beta}} \qquad (7.\ 14a)$$

Substituting (7.144) in (7.3), the aggregate demand for labour is as follows:

$$N_Y = \left[\frac{B(1-\beta)^2}{w} \right]^{\frac{1}{\beta}} \sum_{j=1}^{m} \lambda_j^{\frac{1-\beta}{\beta}} \qquad (7.16a)$$

For mathematical convenience, let's define the "average technology", λ, as follows:

$$m\lambda^{\frac{1-\beta}{\beta}} = \sum_j \lambda_j^{\frac{1-\beta}{\beta}} \qquad (7.4a)$$

Combining (7.16a) and (7.14a), and using (7.4a), one obtains another expression for the sector level labour demands:

$$N_j = \left(\frac{\lambda_j}{\lambda} \right)^{\frac{1-\beta}{\beta}} \frac{N_Y}{m} \qquad (7.5a)$$

Equation (7.5a) extends (7.5) by allowing productivity improvements in each sector not to be synchronized. According to this expression, employment in sector j will be higher or below average, depending on how sector *j*' productivity (λ_j) compares to the economy average, λ. In a sector with productivity equal to the economy' average, $\lambda_j = \lambda$, employment will be equal to the average (7.5). Equation (7.5a) implies a "crowding out effect", whereby sectors with fast productivity growth expand and absorb workers released from non-innovating sectors, eroding their profits. This "crowding out" effect, mediated by wages, arises as a negative externality of vertical innovations to laggard firms.

Solving for w in (7.16), one obtains $w=(1-\beta)^2 B(m/N_Y)^{\beta} \lambda^{1-\beta}$. This equation shows that, given the labour supply, N_Y, the wage rate increases with both vertical and horizontal innovations. Using this expression in (7.6). the equilibrium wage rate as a function of total income becomes:

$$w=(1-\beta)^2 \frac{Y}{N_Y} \qquad (7.17a)$$

Individual profits can then be rewritten substituting (7.5a) in (7.13) and using (7.17a):

$$\pi_j = \beta(1-\beta)\frac{Y}{m}\left(\frac{\lambda_j}{\lambda}\right)^{\frac{1-\beta}{\beta}} \qquad (7.18a)$$

Equation (7.18a) mantains that monopoly profits in each sector depend negatively on the market share (*1/m*), thorough the *dilution effect*. The novelty is that profits in each sector depend on how the sector productivity (λ_j) relates to the economy' average (λ). Together, equations (7.5a) and (7.18a) reveal that asynchrony in vertical innovations cause labour and profits to reallocate across sectors. Employment and profits will increase in innovating sectors and will decrease in non-innovating sectors.

In sum, profits in each sector depend on the productivity in that sector, but also on the technological developments in other sectors. It is the combined effect of all technological improvements that determines the wage rate and by then, expected profits and the incentives to innovate.

Appendix 7.2. The equilibrium level of R&D

In this appendix, we show how the economy-wide equilibrium level of R&D can be determined in the context of our model, focusing on vertical innovations. In our model, investment in R&D is carried out by workers deviated away from production (equation 7.7). Hence, the term F in equation (7.23) basically refers to the cost of devoting working time to research. Since labour is homogeneous and freely mobile across sectors, the cost of allocating workers to research can be measured by the foregone wages that otherwise could be earned in final good production. Since each sector is small, it takes the wage rate as given. With this ingredient, the model develops in an intuitive manner: labour is deviated away from production with the aim to obtain rents. Depending on how expected rents compare to the wage rate, workers allocate their time to R&D or to output production. At the margin, a worker must be indifferent between allocating one unit of time to output production or to research.

Assume that R&D efforts are aimed to achieve productivity gains along existing product lines (vertical innovations). To abstract from complications related to asynchronized technological change, we focus on the "average sector", where $\lambda_j = \lambda$, and we assume that all innovations are drastic and proportional[136]. As for horizontal innovations, the number of varieties *m* is assumed to spring automatically in proportion to the size of population, in line with conventional models of monopolistic competition[137].

Suppose that the current technological level in the average sector is λ_0. It is assumed that, when *one* unit of labour is devoted to the search for technology λ_1, that technology will

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[136] More specifically, we assume that $\lambda_2/\lambda_1 = \lambda_1/\lambda_0 = ... = 1/(1-\beta)$. This is a necessary assumption for the equilibrium μ to be constant over time.

[137] Authors following this direction include Dinopoulos and Thompson (1998) and Peretto (1998) [Dinopoulos, E. and Thompson, P., 1998. Shumpeterian growth without scale effects. Journal of economic growth 3(4), 313-35. Peretto, P. "Technological change and population growth", 1998. Journal of Economic Growth, 3(4), 283-311].

be discovered with probability b. At the sector level, the probability of the next vintage λ_1 being discovered is proportional to the total time allocated to R&D in that sector, $\mu N/m$:

$$q = b\mu\left[N/m\right] \qquad (7.22a)$$

Since we are assuming that the number of sectors m increases along with the size of population, the number of researchers per variety remains constant. This is an important property of the model: most endogenous growth models are plagued by a scale effect whereby the growth rate of per capita output becomes a function of the size of population. This model gets rid of the scale effect assuming that the number of varieties expands along with the size of population. This allows the number of researchers per variety to remain unchanged. Since the arrival of new technologies depends on the number of researchers per sector, the average productivity growth is unaffected by the size of population.

The arbitrage condition (7.23) is now re-written considering the decision to allocate one unit of time to work in the formal sector versus R&D. Hence:

$$b\left[\frac{\pi_1}{r + b\mu\left(N/m\right)}\right] = w_0 \qquad (7.23a)$$

In (7.23a) the wage rate refers to the period pre-innovation, while profits are generated after innovation[138]. Under full monopoly in all sectors, the equilibrium wage rate obeys to (7.17a). Using (7.7), this gives:

$$w_0 = \left[\frac{\left(1-\beta\right)^2}{1-\mu}\right] y_0 \qquad (7.17b)$$

where $y_0 = Y_0/N_0$ denotes for per capita output. This equation relates the wage rate to the proportion of time allocated to R&D at the economy-wide level, μ: because there are

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[138] Also note that, because of the stochastic nature of innovations, the period of time between two successive innovations in this model has a random length.

decreasing marginal returns to labour (equation 7.6), the more labour in the economy is deviated away from production to R&D, the higher will be the wage rate, and henceforth the higher the opportunity cost of research. With this mechanism, the equilibrium level of R&D will be in general an interior solution.

When all sectors are alike, monopoly profits are given by (7.18). Multiplying and dividing both sides by population, we get:

$$\pi_1 = \beta(1-\beta)y_1\left(\frac{N}{m}\right) \quad . \qquad (7.18b)$$

Per capita income evolves according to (7.8). Since we are assuming that the number of varieties increases proportionally to the size of population, the only source of per capita income growth is λ, that is $y_1 = (\lambda_1/\lambda_0)^{1-\beta}\, y_0$. Using this to solve together (7.18b) and (7.17a) and substituting in (7.23a), the equilibrium level of R&D becomes:

$$\mu = 1 - \frac{1+(r/b)(m/N)}{1+(\lambda_1/\lambda_0)^{1-\beta}\,\beta/(1-\beta)} \qquad (7.24a)$$

Equation (7.24) states that the optimal proportion of time devoted to R&D in the economy will be higher, the lower the interest rate, the higher the productivity of R&D, *b*, and the larger the technological jump, λ_1/λ_0. It is also apparent that μ is an increasing function of β: the lower the elasticity of the demand curve faced by the intermediate monopolist, the larger the monopoly rents that will be appropriated by successful innovators and hence the larger the incentives to innovate. This accords to the Schumpeter view that market power is good for innovation.

Problems and Exercises

Key concepts

- *Horizontal vs. vertical innovation. Division of labour. Drastic vs. non-drastic innovation. Static vs dynamic efficiency. Limit Pricing. The appropriability Effect. Creative destruction .Business stealing Effect. Neck and neck competition*

Essay questions:

- Comment: “Competition is bad for growth”.

- Comment: "Patents are inefficient. One could banish them and still have incentives for R&D".

Exercises

7.1. (**Vertical vs horizontal**) Consider a restaurant, where output (Y) refers to the number of meals produced. The production function is $Y=\sum_{j}^{m} x_j^{1/2}$, where *x* refers to the number of tasks used in the production process. Assume that there are 4 employees (N_Y), each one with productivity equal to λ=9. (a) Assume first that there was only one job profile (m=1), consisting in cooking, collecting the costumers' orders, serving and washing the dishes. (that is, each worker does all the tasks). Find the number of chairs produced by the carpenter. (b) Now consider a technological improvement, consisting in splitting the initial job profile into four specialized tasks (m=4), each worker becoming specialized in one task. Explain the impact on production. (c) What would be the impact if the productivity of each worker increased from λ=9 to λ=25? (d) Referring to the exercise, explain the difference between vertical innovations and horizontal innovations. Is the example referring to process innovations or to product innovations?

7.2. (**Drastic, non-drastic**) Consider an economy where the aggregate output is assembled with *m* intermediate inputs: $Y=B\sum_{j=1}^{m} x_j^{1-\beta}$. The production function of each intermediate input is given by: $x_j = \lambda \ N_j$ and the total labour force employed in the intermediate input sector as a whole is expressed as: $N_y = (1-\mu)N = \sum_{j=1}^{m} N_j$. μ is the constant fraction of the labour force devoted to R&D. The wage rate (*w*) is 50, β=1/3, B=100 and λ=2.(a) If the final good sector was perfectly competitive, what would be the demand for input j? (b) If only one producer had the right to produce j, what would be the corresponding price? Represent in a graph. (c) If, in alternative, imitators could produce this variety with a marginal product equal to λ_F=1.6, what would be the equilibrium? Explain, with the help of a graph. (d) Assume now that a firm escaping competition developed a more efficient technique to produce good j (λ= 2.5). Would this innovation be drastic or non-drastic? Explain with the help of a graph.

7.3. (**Value of the horizontal innovation**) Consider an economy where the demand for each intermediate input is given by $p_j = 20x_j^{-0.5}$. In this economy, technology in each sector is given by $x_j = N_j$, the interest rate is r=25% and the wage rate is W=1. (a) Consider the problem of an entrepreneur trying to discover a new intermediate input, j. (a1) How do you classify this innovation? (a2) What mechanism does this type of innovation influence per capita income? (a3) If the innovator becomes a monopolist in this sector, what will be the optimal amount and price? (a4) and profit? (a5) Represent graphically the welfare gain associated with this innovation, in the case of monopoly. (a6) Identify in the figure the additional welfare gain after the monopoly is eliminated. (b) Consider the entrepreneur's problem again, but before starting the R&D activity. Analyze the incentives for innovation, knowing that the activity involves an initial fixed cost of F=80 and a probability of success at the end of the year equal to b=50%, knowing that the patent would last: (b1) eternally? (b2) one year? (b3) two years? (b4) What is the ideal duration of a patent (in years), taking into account the static and dynamic benefits? (b5) Explain.

7.4. (**NPV of vertical innovation**) Consider an economy where demand for each intermediate product is given by $p_j = 100 x_j^{-0.5}$. Initially the market for this product is competitive, being $\lambda_F = 0.5$. It is also known that the interest rate is r=5% and that initially the salary in this economy is W=1. (a) Consider the problem of an entrepreneur who has discovered a new way to produce this good, given by x=2N . (a1) How do you classify this type of innovation? If the innovator becomes a monopolist in this sector, what will be (a2) the optimal production; (a3) the price? (a4) profit? (a5) Will this innovation be drastic or not drastic? (a6) Represent graphically the welfare gain resulting from this innovation, under monopoly. (a7) Identify in the figure the additional welfare gain when the monopoly is eliminated. $x = 2N$ (b) Assume now that the entrepreneur was still thinking in inventing this product. Analyze the decision of engaging or not in R&D, taking into account a fixed cost F=1500 and the probability of discovery equal to b=10%. In particular, discuss the cases in which: (b1) the innovation becomes immediately available to all competitors; (b2) the probability of arrival of a superior technology each year is 0%; (b3) the probability of arrival of a superior technology each year is 20%. (b4) Which of these situations is more interesting from the firm point of view? Represent in a graph (b5) Which of these situations is more efficient from the dynamic point of view? Discuss, taking into account the different possible effects.

7.5. (**Value of horizontal innovation, division of labour**) Consider an economy where the final good sector (Y) has the following production function $Y = 80\sum_{j}^{m} x_j^{0.5}$, where m denotes for the number of intermediate products. In this economy, technology in each sector is given by $x_j = 0.25 N_j$, the interest rate is r=25% and initially W=1. (a) Assuming perfect competition in the market for the final product, and defining p_j as the price of intermediate input j. Find out the demand for each input. (b) Consider the problem of an entrepreneur trying to find a new intermediate product, j. (b1) How do you classify this type of innovation? Define it. Assuming that the entrepreneur achieved a monopolist position, find out: (b2) The optimal production: (b3) The optimal price; (b4) The profit (c) (c1) What would be the value of this innovation if the technology became available at zero cost immediately after the innovation? (c2) In that case, what would be the equilibrium price and the quantity demanded? (c3) Represent in a graph, comparing with (b). (c4) From the social point of view, would be more efficient the outcome (c) or (d)? Discuss. (d) Assume that the entrepreneur still didn't find the technology described in (b). Analyse the decision of trying to invent it, taking into account that the probability of inventing was b=10%, with a certain fixed cost equal to F=20. In particular, what will be the optimal decision if: d1) The probability of the profits disappearing after period 1 was 15%. d2) The probability of the profits disappearing after period 1 was one. d3) Whish probability would turn the entrepreneur indifferent? d4) In the real life, which factors influence that probability? (f) Return to you results in (b): e1) If in this economy there were $N_Y = 1600$ workers and sectors were all alike, how many sectors would exist in the economy? How much would be per capita in income in that case? e2) All else equal, if the number of sectors increased to m=25, what would happen to the number of workers in each sector and to per capita income? e3) What is the effect underlying the productivity change? Explain it (1 line) e4) Find out the demand for labour in each sector as a function of the wage rate. Compute the impact of the increase in m to 25 on the wage rate.

7.6. (**Vertical innovation**, **Competition)** Consider the market of an intermediate input, which individual production function and market demand are described by $x_i = \lambda_i N_i$ and $p = 1.5x^{-1/3}$, respectively. Also assume that this market is small relative to the rest of the economy, with W=1. Initially, this product is produced under perfect competition, with $p = W/\lambda = 0.75$. (a) Assume that an entrepreneur achieved a technology to produce this good with λ=1.6. Is this innovation vertical or horizontal? The innovation just described is drastic or non-drastic? Explain the optimal strategy of the entrepreneur and the corresponding profit. Represent in a graph. (b) For this strategy to materialize, which condition shall be verified? Identify real world mechanisms that help this condition to be verified. (c) Assume now that more entrepreneurs were able to achieve the same technology λ=1.6, and divided equally the implied profits. Discuss the effect of the increasing competition in this market on the incentives to innovate, distinguishing entrepreneurs from the fringe and entrepreneurs already using the leading technology.

7.7. (**Vertical innovation, neck and neck**) Consider an economy where the production function in the final good sector is given by $Y = 40K^{0.5}x^{0.5}$, where x refers to an intermediate input, and K=1. In the intermediate good sector, the production function of each individual firm is given by $x_i = \lambda_i N_i$. Also assume that this market is small relative to the rest of the economy, with W=5. (a) Find out the demand for the intermediate input, assuming perfect competition in the final good sector. In this market, R&D costs are paid by each firm to their own research departments, but in the form of an *annual royalty* (F). (b) Assume that this market was explored by an incumbent monopolist holding the technology $x = 2N$. What would be its optimal price and operating profit? What would be the net profit, after paying the annual royalty amounting to F=5? (c)Suppose that a second entrepreneur managed to join the frontier and share the profits with the incumbent, at the annual cost F=5. (c1) would that innovation be profitable from the private point of view? (b2) and from the social point of view? (c3) which externalities are involved in this case? (c3) would be profitable for other entrepreneurs to join the frontier? (d) Suppose that the original incumbent estimated at F=15 the (flow) cost of achieving $\lambda = 2.5$. Would this investment be worthwhile? Explain the underlying effect.

7.8. (**N&N, leakages**) Consider the market of an intermediate input, which total demand is given by $p = 4x^{-1/2}$. Assume that this market operates initially under perfect competition, and that the production function of each individual firm is given by $x_i = \lambda_F N_i$, where $\lambda_F = 1$ stands for the technological level at the fringe. Further assume that this market is small relative to the rest of the economy, with W=1. Inventions are exclusive to each firm, but the reward of the research department by the firm consists on annual royalty (F), that is only paid in case the technology generates profits. (a) In the initial equilibrium: (i) price is equal to 1; (ii) the total demand for labor is 16 (iii) total demand is x=16; (iv) all the above. (b) Assume that an entrepreneur discovered a way of producing the product with the technology $x = 4N$, and kept it secret. This innovation will be: (i) a drastic product innovation; (ii) a non-drastic product innovation; (iii) a drastic process innovation; (iv) a non-drastic process innovation. (c) In the equilibrium after innovation: (i) the entrepreneur' operational profits will be 16; (ii) production will be x=16; (iii) employment will be 64; (iv) none of the above. (d) Assume that the use of the new technology involves an annual royalty equal to F=24. This innovation will come at: (i) private gain, social loss; (ii) social loss, private loss; (iii) private gain, social gain; (iv) private loss, social gain. (e) Departing from (g) assume that a second entrepreneur was able to discover technology $\lambda = 4$, running an annual R&D cost equal to F=3. Assuming that profits would be equally shared by the two entrepreneurs, this innovation will be: (i) socially efficient; (ii) socially inefficient; (iii) unprofitable from the private point of view; (iv) we can't say. (f) Sticking with the assumption that the R&D cost needed for each entrepreneur to join the frontier was F=3 and that profits at the front were equally shared, what would be the maximum number of competitors at the front so that innovating to join it was still interesting? (i) 3; (ii) 5; (iii) 6; (iv) can't say. (g) Now, consider the incentives for an entrepreneur at the frontier spending F=25 in the patent for the next vintage, $\lambda = 8$. What would be the critical number of competitors at the frontier so that it became attractive for this entrepreneur to innovate and escape? (i) 1; (ii) 2; (iii) 3; (iv) 4. (h) Returning to g), assume that after technology $\lambda = 4$ was discovered (t=0), knowledge started leaking at zero cost to the competitive fringe, so that technology at the fringe λ_F expanded at the pace of $\lambda_{F,t} = \lambda_{F,t-1} + 0.5(\lambda - \lambda_{F,t-1})$. In that case, what would be the right time for the leader to spend F=25 in the new patent and adopt the next vintage $\lambda = 8$? (i) t=3; (ii) t=4; (iii) t=5; (iv) t=5.

7.9. (**Value of Vertical, N&N**) Consider an economy where the demand for a particular sector is given by $p = 16x^{-0.5}$. It is also known that the interest rate is r=25% and that initially the salary in this economy is W=1. (a) Assume that initially the market for this product was competitive, being $\lambda_F = 0.5$. a1) Determine the price and quantity produced in this market. (b) Consider the problem of an entrepreneur who has discovered a new way to produce this product given by $x = 0.8N$. (b1) How do you classify this innovation? Define it (1 line) Assuming that the innovator became monopolistic in this sector: (b2) Determine the optimal amount of production:(b3) The optimal price of the monopolist (b4) Will this innovation be drastic or not drastic? (b5) Show in graph. (b6) Find out the operating profit (b7) Was this innovation socially desirable? Identify the possible gains and losses for each group (consumers, producers, entrepreneur). (c) (c1) What would be the value of this innovation if the probability of profits disappearing in the following year was q=1? c2) And if the probability of profits disappearing each year is q=0.25? Comment, comparing with c1 (1 line). (c3) In real life, what factors influence the probability q? (d)Now consider the problem of a second entrepreneur who wanted to discover exactly the same technology (joining the frontier), to share the market with the incumbent for only one year. d1) Would such innovation result in social welfare gain? What are the two externalities at stake here? d2) Admit that imitation involved a fixed cost of F=17.5 and a probability of success of b=100%. In this case, would it be interesting for the entrepreneur to try the imitation? d3) What if there was already another entrepreneur under equal circumstances in the race? (d4) What do you conclude about the intensity of competition and incentives for innovation? What effect is at stake here? This is the general case?

7.10. (**Equilibrium R&D partial equilibrium**) Consider an economy where the demand for each intermediate input is given by $p_j = 2x_j^{-0.5}$. In this economy, the interest rate is r=7.5% and the wage rate is W=1. (a) Consider the problem of an entrepreneur trying to discover a new intermediate input, *j*. (a1) How do you classify this innovation? (a2) Through which mechanism does such an innovation impact on per capita output? (b)

Assume that the production function for this new product is expected to be $x_j = N_j$. In case the innovator succeeds and becomes monopolist, how much will be its output and profits? (a4) Represent in a graph. (c) Analyze the decision of engaging or not in R&D, taking into account a fixed cost F=1, the probability of discovery b=0.1, and the probability of being displaced by a drastic innovation, *q* equal to: (c1) q=0; (c2) q=0.005; (c3) q=0.25? What would be the corresponding NVP? (d) Finally, assume that $q = b\mu = 0.1\mu$. (d1) explain this assumption; (d2) If fixed costs were the same for all firms, what would be the equilibrium level of R&D in this case? Explain, with the help of a graph.

7.11. (**Equilibrium R&D**) Consider a product, which production is carried by an incumbent that is monopolist in the product market and price taker in the labour market. The demand curve for this product is given by $p = 2x^{-1/2}$ and the production function is equal to $x = \lambda N_Y$, where $N_Y = (1-\mu)N$ is the proportion of working time that workers in this sector devote to production. The workers' remaining time is devoted to private R&D, in an attempt to achieve a vertical innovation and displace the incumbent. When 1 unit of labour is devoted to R&D, the probability of achieving a vertical innovation consisting multiplying the previous lambda by four is b=1%. The total working time in this sector is constant and given by N=5.(a) Consider first the problem of the incumbent monopolist, who achieved a productivity level (λ) equal to 4. Taking into account that the wage rate (w) is equal to 1, find out the selling price and the production level that maximize the incumbent' profits. Compute these profits and represent the monopolist' optimal solution in a graph. [0.5, 16] (b) Taking now the wage rate and the productivity parameter as unknowns, find out the general expression of the operational profits in this sector. (c) Taking now the wage rate and the productivity parameter as unknowns, find out the general expression of the demand for labour in this industry. Show that the wage rate is a negative function of $(1-\mu)$. What will be the demand for blue collars when λ=4 and W=1? (d) Consider now the problem of a research worker that is trying to discover technology λ=16. If he succeeded and became monopolist (displacing the incumbent), how much would be his profits? (hint: don't forget the impact of innovation on wages, and consider $(1-\mu)$ as unknown). (e) Taking into account the probability of achieving a vertical innovation (b=1%) and assuming that the discount rate is equal to r=7%. what proportion of his time should he devote to R&D?