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JEAN TIROLE: MARKET POWER AND REGULATION

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1 Introduction

To what extent should the government intervene in the marketplace? Economists often consider fiercely competitive markets to be in the public interest. When producers in such markets strive to earn a profit, they are led – as if by an invisible hand – to deliver high quality at low cost.[1] But many industries are not very competitive, and this lack of competition widens the scope for beneficial public intervention. Theories of regulation and competition policy aim to provide useful scientific guidance for such intervention. Clearly, any recommendations must rest on a sound understanding of how imperfectly competitive markets work. When a firm has market power, how will it behave? How does its behavior affect the firm's suppliers, customers, and competitors? Questions like these are studied within the field of Industrial Organization (IO). George Stigler was awarded the 1982 Prize in Economic Sciences "for his seminal studies of industrial structures, functioning of markets and causes and effects of public regulation". Since then, however, the IO field has undergone rapid development, indeed a revolution. This revolution has greatly enhanced our understanding of imperfectly competitive markets, which in turn has laid a foundation for better informed competition policy. Comparable progress has been made in the theory of optimal regulation of firms with market power.

The progress in these areas largely reflects two methodological breakthroughs: game theory and the theory of mechanism design.[2] By the end of the 1970s, the time was ripe for applying these tools to the major issues of imperfect competition, regulation, and competition policy. Over the next decade, many economists were drawn into these fertile fields. The analytical revolution was to a large extent a collective effort but, among many contributors, Jean Tirole stands out. No other scholar has done more to enhance our understanding of IO in general, and of optimal policy interventions in particular.

The theoretical advancements coincided with a period of great public-policy interest in the same issues. During the 1980s and 1990s, many countries pursued regulatory reforms and pro-competitive liberalization – sometimes in conjunction with privatizations. The European Union created the single market. Many new issues arose that could not be fruitfully studied with the help of existing theory – their analysis required a combination of oligopoly theory and contract (principal-agent) theory and an integration of industrial economics with public economics. Tirole's expertise spans all these fields, and he was thus ideally positioned to make a lasting contribution.

[1] Of course, there are exceptions to this rule. For example, if customers are poorly informed, or if the firms' activity entails negative externalities, competition might be detrimental. However, here we are concerned with markets where those problems do not create major difficulties.

[2] A Prize in Economic Sciences was awarded in 1994, to John Harsanyi, John Nash, and Reinhard Selten for game theory, with a focus on non-cooperative solution concepts. Game theory was also central to the 2005 Prize to Robert Aumann and Thomas Schelling, for their analysis of conflict and cooperation. The 2007 Prize was awarded to Leonid Hurwicz, Eric Maskin, and Roger Myerson for mechanism design theory. Related awards, for the investigation of more specific mechanisms, include the 1996 Prize to James Mirrlees (taxation) and William Vickrey (auctions) and the 2012 Prize to Lloyd Shapley and Alvin Roth for their analysis of matching markets.

Before discussing the specifics, let us emphasize that Tirole's overall scientific contribution is greater than the sum of his individual contributions. He has created a unified framework for IO theory and regulation, founded on a rigorous analysis of strategic behavior and information economics. It is hard to do justice to his immense body of work in a few introductory paragraphs, but a few features of his research do loom large.

First, Tirole has established a new standard of rigor in the fields of IO and regulation. He has consistently derived his results from fundamental assumptions about preferences, technologies (including contracting technologies) and information asymmetries, eschewing the convenient but *ad hoc* assumptions that had previously seemed necessary in order to make analytical headway. From the outset, Tirole's approach has required unusual technical expertise, especially in the rapidly evolving fields of game theory and contract theory. While this year's prize emphasizes Tirole's creative application of these analytical tools to regulation and IO theory, it is noteworthy that Tirole also made significant contributions to the toolbox itself (see Section 6).

Second, Tirole's rigor has facilitated realism. Division of labor in the scientific community frequently encourages theorists to specialize in understanding the inner logic of new models, leaving the challenging job of confronting the models with reality to more applied scientists. As a result, theoretical work sometimes seems detached from "the real world" and "relevant practice". By contrast, Tirole has carefully designed his models to capture essential features of specific economic environments, and to highlight important mechanisms that previous applied research had either ignored or failed to articulate with sufficient precision.

Third, Tirole has brought order to an unwieldy literature. By deploying a consistent conceptual framework over a wide range of issues, he became a leader in the creation of the first encompassing and coherent theory of IO. After more than 25 years, his groundbreaking 1988 textbook remains the best road-map to the field. If the book is becoming outdated in a few areas, this is largely due to Tirole's own subsequent work and the work he has inspired. Tirole's 1993 book, co-authored with Jean-Jacques Laffont, presented a unified framework which has deeply influenced how economists think about regulation.

Fourth, Tirole's models have sharpened policy analysis. Focusing on the fundamental features that generate a divergence between private and public interests, Tirole has managed to characterize the optimal regulation of specific industries. Often, his rigorous thinking has overturned previous conventional wisdom. For example, he successfully challenged the once prevalent view that monopoly power in one market cannot be profitably leveraged into another market by vertical integration. As a result, competition authorities have become more alert to the potential dangers posed by vertical integration and restraints. More generally, Tirole has shown how the justifications for public intervention frequently boil down to problems of information asymmetries and credible commitments. These general lessons – together with a catalogue of specific applications – form a robust foundation for policy analysis.

In this document, we briefly summarize Tirole's most important contributions to the theory of IO and the regulation of dominant firms. We start in Section 2 with his seminal work on the public regulation of a natural monopoly, most of which reflects a long-standing collaboration with Jean-Jacques Laffont.[3] This work was mostly published

[3] Sadly, Jean-Jacques Laffont passed away much too young in May 2004.

in the period 1986 to 2001 and is summarized in Laffont and Tirole's encyclopedic 1993 book. It builds a coherent foundation for regulation theory, replacing *ad hoc* assumptions with explicit contracting frictions (such as asymmetric information and limited commitment). Many insights are quite general and apply to most regulatory settings, as well as to the related topic of government procurement. Among the most significant advances are the modelling of regulatory capture (collusion between regulatory agencies and regulated firms) and dynamic contracting. These advances were inspired by fundamental contributions to contract theory: Tirole (1986a), Freixas, Guesnerie and Tirole (1985) and Hart and Tirole (1988). The importance of these contributions extends far beyond regulation and procurement.

Although general theories can be of great value, in the end all regulation must be industry-specific. This point is illustrated by example in Laffont and Tirole (2000), where they consider the regulation of the telecommunications industry, as well as in Tirole's studies of other industries, ranging from banking to electricity. The research on the regulation of specific industries illustrates Tirole's exceptional ability to grasp the central features of an economic environment, to formulate these features mathematically, to analyze the resulting model, and to produce normative conclusions of great practical significance.

Although the motivation for the prize focuses on normative theories of optimal regulation and competition policy, any normative theory must rest on a positive analysis of how firms interact. For competition and regulation policy, it is especially important to understand interaction in imperfectly competitive markets. Therefore, *oligopoly theory* is the most central topic in IO. Jean Tirole played a major role in the transformation of oligopoly theory during the 1980's. Among his many contributions to this field, we emphasize his work on strategic investments and R&D races (with Drew Fudenberg and others), on dynamic oligopoly (with 2007 Economics Laureate Eric Maskin), and on co-marketing (with Josh Lerner). These contributions are discussed in Section 3.

Section 4 discusses how theoretical advances have changed the way economists think about competition policy. In particular, Tirole has convincingly analyzed public policies regarding vertical contractual relationships. Vertical relationships only require regulation if they impose costs on outsiders that are greater than the benefits to insiders. Thus, a vital element of the analysis is a precise understanding of mutually beneficial contracts between sellers and buyers in a vertical chain – a problem which closely resembles that of optimal regulation of monopolies (discussed in Section 2). Another important element is to understand the nature of strategic behavior towards competitors (discussed in Section 3). Tirole's analysis of vertical contractual relationships quickly gained academic acceptance, and it has contributed to a significant revision of competition policy, especially in the U.S.

As mentioned, Tirole has not only developed general theoretical frameworks of analysis, but also adapted them to the circumstances of specific and quite different industries. Section 5 discusses two such applications, namely to telecommunication and financial intermediation.

Finally, Section 6 briefly describes some of Tirole's many contributions to other topics: general economic theory, financial markets, asset-market bubbles, organization economics, corporate finance, and behavioral economics.

2 The Regulation of Dominant Firms

In some industries, average costs are minimized when production is concentrated within a single firm. When there is scope for rapid innovation, such a market will usually be dominated by the same firm only for a limited period of time, until a new firm makes a superior innovation. While the dominant firm may earn temporary monopoly rents from pricing above marginal cost, those rents might be an acceptable price for society to pay in order to encourage innovation (Schumpeter, 1943).[4]

In other cases, there is little scope for competitive challenges by new and innovative entrants. For example, production may rely on a unique resource or an investment which is prohibitively expensive to duplicate, and the usage of which cannot be completely specified in a contract. Water mains, railroad tracks, and electricity-transmission lines are a few examples. Firms that control such a resource – whether public or private – are called natural monopolies.[5] How can natural monopolies be prevented from exploiting their dominant power at the expense of consumers (and society at large) without making them go out of business? If a monopoly is allowed to price freely, prices will typically be too high and output too low. If the firm is instead forced to price at marginal cost, it may not break even and public funds must be used to cover its losses.[6] The modern theory of regulation characterizes optimal regulation under realistic assumptions about information asymmetries, the distributional concerns of the government, and the social cost of public funds.

After a brief historical background, we describe the basic Laffont-Tirole model of regulation in subsection 2.2. Important extensions to this basic model are discussed in subsections 2.3, 2.4 and 2.5.

2.1 Background

In 1945, Ronald Coase (the 1991 Economics Laureate) pointed out a problem in deciding whether to use public funds for subsidies to a natural monopoly. To make the right decision, the government must know the social surplus (the difference between consumers' valuation and production costs) generated by the firm. Since the social surplus will never be fully revealed by prices, and is particularly obscure under marginal-cost pricing, the informational difficulties are considerable. Coase's (1945) brief discussion highlighted that information problems are crucial in regulation. Subsequent research has focused

[4] That said, there may be better ways to strike a balance between the production and utilization of innovations than allowing unregulated monopoly behavior. This issue turns up in several guises in the coming sections.

[5] Here we focus on the regulation of an existing monopolist. However, the focus of regulatory activity has frequently been the introduction of competition (see Armstrong and Sappington, 2006). We will later discuss Tirole's work on competition in regulated network industries. Even if only one firm is allowed to operate in the market, the government might be able to create competition by auctioning off the right to operate (Demsetz, 1968). We refer to Laffont and Tirole (1987, 1988b), McAfee and McMillan (1986) and Riordan and Sappington (1987) for studies of auctions in a regulatory/procurement context.

[6] Under perfect competition, price equals marginal cost. However, if a firm has increasing returns to scale, perhaps because production involves large fixed costs, then it will operate at a loss if it prices at marginal cost. Under such circumstances, an unregulated market either does not provide the product at all, or involves imperfect competition with prices above marginal cost.

on an even more formidable information problem: the regulator cannot easily observe whether the regulated firm is doing its best to keep production costs low, or how much it would cost to raise output quality. Poorly designed regulation could thus easily entail excessive cost overruns, or insufficient productivity growth, in spite of large subsidies.

Historically, regulators have often relied on simple rules of thumb. With *rate-of-return regulation*, the regulated firm is allowed to set prices above marginal cost, but its rate of return cannot exceed a given level. However, this form of regulation has a number of shortcomings: it gives the firm no real motive to minimize its production costs, since the government compensates the firm for cost increases (by allowing prices to go up), and it encourages the firm to over-invest in capital relative to other inputs (Averch and Johnson, 1962). In fact, rate-of-return regulation lacks a normative justification. For example, what criteria should be used to determine the permitted rate of return? We need a normative framework to rigorously evaluate different regulatory schemes and characterize *optimal* regulation.

Ramsey pricing As long ago as the 1920s, the polymath Frank Ramsey formally characterized the "least inefficient" departures from marginal-cost pricing that would allow a monopoly firm to break even (Ramsey, 1927). But the theory of Ramsey pricing entailed no clear justification for the break-even constraint: why are subsidies to the firm ruled out? Moreover, the informational requirements of Ramsey pricing are significant. In theory, the regulator must know both cost functions and demand functions to compute the optimal prices. In reality, the firm's management may have superior information about both.

In the late 1970s, a number of researchers studied how the regulator might bypass these problems by decentralizing pricing decisions to the regulated firm. Vogelsang and Finsinger (1979) argued that a regulator with no knowledge of cost or demand functions could use iterative rate-of-return regulation to implement long-run Ramsey pricing. The average price a firm could charge in the current period would depend on the prices it charged in the previous period and on its observed production cost. If the firm chooses its prices myopically in each period – a very strong assumption – then this dynamic process would converge to Ramsey pricing. Loeb and Magat (1979) argued that a regulator who knows the demand function but not the cost function might be able to implement the *first-best* marginal-cost pricing outcome. Assuming the regulator (i) can use non-distortionary taxation to finance lump-sum subsidies, so that Ramsey-pricing is not necessary, and (ii) assigns the same welfare weights to consumer surplus and firm profit, so that distributional concerns are absent, the Loeb-Magat solution effectively hands the entire social surplus to the firm. Indeed, the principal-agent literature teaches us that allocative efficiency is obtained if a risk-neutral agent (here, the firm's manager) is a residual claimant to the surplus. However, real-world governments usually have distributional concerns that rule out such one-sided outcomes. Moreover, with distortionary taxation, or more generally in the presence of distortions elsewhere in the economy, the case for Ramsey-pricing re-emerges (e.g., Hagen, 1979). Public funds have an opportunity cost, and handing surplus to the managers or owners of regulated firms hence also entails a loss of efficiency in the overall economy.

Towards a mechanism-design approach Under realistic assumptions about the government's objectives and informational asymmetries, the regulator must thus balance the efficiency of the regulated firm against the social value of extracting the firm's rents. In 1982, David Baron and 2007 Economics Laureate Roger Myerson studied this problem without imposing any *ad hoc* restrictions on the regulatory scheme. This initiated the modern mechanism-design approach to regulation. However, Baron and Myerson (1982) assumed that the regulated firm's cost function is given and immutable. This assumption rules out production inefficiencies and cost overruns, problems that are central in many regulated industries. Sappington (1982) took an important step forward. He endogenized the cost function by assuming the regulated firm can take unobserved actions to reduce its production cost. However, by restricting the regulator to offering linear contracts, Sappington (1982) left an important question unanswered: what is the optimal shape of the regulatory contract?

2.2 The Basic Laffont-Tirole Model of Regulation

Laffont and Tirole (1986) applied the tools of mechanism design to a model with endogenous cost functions, similar to that previously studied by Sappington (1982). This Laffont-Tirole model treats regulation as a principal-agent problem, with the government or "regulator" as the principal, and the regulated firm (or more precisely, its manager) as the agent. The regulator observes realized production costs, but not how much effort the firm has put into cost-reduction (a post-contractual hidden effort problem). Moreover, the firm knows more about its cost-reducing technology than the regulator (a pre-contractual hidden information problem). Importantly, Laffont and Tirole (1986) imposed no restrictions on the set of feasible regulatory mechanisms, except the restrictions that follow from the information asymmetries and voluntary participation of the firm.

Assumptions We consider a simplified version of the basic model, where the government procures an indivisible public good from a privately owned firm. The good is completely financed by a transfer t from the government to the firm; individual consumers pay nothing.[7] The regulator in charge of procurement observes the firm's realized production cost C. Thus, the transfer t can depend on C, allowing us to study optimal cost-sharing between the government and the firm. The shadow cost of public funds is $1 + \lambda$, where distortionary taxation implies $\lambda > 0$. The regulator seeks to maximize total social surplus $S + U - (1 + \lambda)t$, where S is consumer surplus and U is the utility of the firm's manager. Specifically, $U = t - C - \Psi(e)$, where $e \geq 0$ is the effort exerted to reduce production cost, and $\Psi(e)$ is the manager's cost of effort (an increasing, strictly convex function). The production cost is $C = \beta - e$, which depends on two factors: (i) it is increasing in efficiency parameter β, the firm's cost-type, drawn from an interval $[\underline{\beta}, \overline{\beta}]$ (the distribution is assumed to be continuous and to satisfy the so-called monotone

[7]Procurement can be distinguished from regulation based on who receives the good: the government (procurement) or consumers (regulation). For our purposes, the distinction is immaterial, as the Laffont-Tirole model is applicable in both cases. The general model, where consumers can be charged a (regulated) price, is treated at length in Laffont and Tirole (1993).

hazard-rate property), and (ii) it is decreasing in the manager's effort e.[8] The manager learns his firm's true cost-type β and chooses e. The regulator observes C but not β or e. Thus, the regulator encounters hidden information (unobserved β) as well as hidden action (unobserved e). Low-cost types (low β) are inherently more efficient than high-cost types (high β). Whatever his type, the manager can reduce the production cost by working hard. Since the marginal benefit of effort is 1, and the marginal cost of effort is $\Psi'(e)$, the *first-best* effort level e^* satisfies $\Psi'(e^*) = 1$.

Using the definition of U, social surplus is $S - C - \Psi(e) - \lambda t$. All else being equal, the regulator prefers as small transfers t as possible, as every dollar transferred implies a net social loss of $\lambda > 0$. However, the regulator must make sure that three constraints are satisfied: (1) a *participation constraint*: each type of manager must participate voluntarily, which requires $U \geq 0$;[9] (2) a *moral-hazard constraint*: as the regulator does not observe e, the transfer scheme (mechanism) must motivate each manager to supply an appropriate effort level; and (3) an *incentive-compatibility* (or *self-selection*) *constraint*: as the regulator does not observe β, the manager must voluntarily choose the appropriate contract for his own cost-type.

Analysis Laffont and Tirole (1986) showed that the optimal transfers consist of a lump-sum payment plus a linear cost-sharing term. Specifically, the optimal mechanism can be expressed as follows. After having observed β, the manager announces his expected production cost C^a. Then, production takes place and the actual production cost C is observed by the regulator. The cost overrun is $C - C^a$ (which, if negative, is actually a cost saving). The transfer is given by the cost-reimbursement rule $t = t(C^a, C)$, where

$$t(C^a, C) \equiv a(C^a) + b(C^a) \times (C - C^a).$$

Here $a(C^a)$ is a lump-sum transfer, and $b(C^a)$ is the share the regulator pays of any cost overrun. Notice that $a(C^a)$ and $b(C^a)$ do not vary with the realized cost C, but do depend on the announced C^a. The mechanism can therefore be expressed as a *menu of contracts*. Self-selection requires the manager to truthfully announce his expected cost C^a so that he receives the contract which is appropriate for his type.[10] Each contract is characterized by $a(C^a)$ and $b(C^a)$, and incentives are more high-powered if $b(C^a)$ is small. If $b(C^a) = 1$ then the contract is *cost-plus*: the regulator pays 100% of any cost overrun. Cost-plus contracts are in general not optimal, because they provide no incentives for cost-reduction (the manager would set $e = 0$).

Laffont and Tirole proved that $b(C^a) = 0$ for the lowest cost-type ($\beta = \underline{\beta}$), who naturally announces the lowest C^a. Thus, the most efficient firm gets a *fixed-price* contract where the transfer $t(C^a, C) = a(C^a)$ is purely lump-sum – i.e., independent of realized cost C. The incentives to reduce costs are then high-powered, and the manager supplies the first-best effort. Giving such high-powered incentives to *all* types would be socially very costly, however. High-cost types would need a very large lump-sum transfer to induce

[8] Since both the regulator and the manager are assumed risk-neutral, a random disturbance to the production cost can be introduced in the basic model without changing any results.

[9] The manager's outside option is to exit the industry (and produce nothing).

[10] Higher cost-types will expect to have higher production costs, so announcing C^a is equivalent to announcing β.

them to participate in a fixed-price scheme. But managers of efficient firms could always pretend that cost conditions are unfavorable (by announcing a high C^a), so incentive compatibility would force the regulator to give them very large lump-sum transfers as well – even though their realized costs will in fact be low. Therefore, high-powered incentives for high-cost types imply large (and socially costly) *information rents* for low-cost types.

Results: rent extraction vs. cost reduction Due to the social cost of public funds, the regulator must balance cost-reducing incentives for high-cost types against rent extraction from low-cost types. The optimal mechanism gives all managers with $\beta > \underline{\beta}$ contracts with $b(C^a) > 0$. These *incentive contracts* specify that the government reimburses the firm for a fraction $b(C^a) > 0$ of the realized cost. Since the firm only pays a fraction $1 - b(C^a) < 1$ of cost overruns, the manager's cost-reducing effort is strictly less than the first best. However, as $b(C^a) < 1$, cost overruns are not fully reimbursed. All types except the most inefficient one earn information rents: $U > 0$ for all $\beta < \overline{\beta}$. These rents are socially costly, and the regulator could eliminate them by cost-plus contracts, but does not do so because this would also eliminate the incentives to reduce costs.

For future reference, we refer to the optimal regulatory mechanism derived by Laffont and Tirole (1986) as the *optimal static mechanism*, or *o.s.m.* As we have seen, the *o.s.m.* has the following three key properties: (S1) the manager self-selects by truthfully announcing C^a, and thereby reveals his cost-type, (S2) each type $\beta > \underline{\beta}$ provides less than first-best effort (i.e., $e < e^*$), and (S3) each type $\beta < \overline{\beta}$ receives an information rent (i.e., $U > 0$).

Impact Laffont and Tirole (1986) was published at a time when different regulatory schemes were hotly debated. Some policies were recognized to have poor incentive properties, leading to huge cost overruns. The trend was to abandon *rate-of-return regulation* in favor of *price-cap regulation*, where in effect the firm becomes the residual claimant for cost savings (as when $b(C^a) = 0$ above). While the poor incentive properties of rate-of-return and cost-plus regulation had already been recognized, the Laffont-Tirole model highlighted a subtle problem with price caps: high-powered incentives imply large rents to efficient firms, which is very costly if public funds are raised by distortionary taxation, or if the regulator has distributional objectives. To reduce these rents, optimal regulation will generally not induce first-best levels of cost-reduction. Thus, observing unnecessarily high production costs does not necessarily reflect badly designed regulation. This important fact plays a key role in dynamic regulation (see subsection 2.4 below).

More generally, by providing a normative framework of optimal regulation, the Laffont-Tirole model clarified the relative merits of different policies. Since real-world policies may not be well designed, it is quite possible that current practice differs from the optimal mechanism.[11] However, for the recommendations to be useful, the model assumptions should approximate the situation facing real-world regulators. The basic framework of the Laffont-Tirole model does seem consistent with empirical observations. For example, the model explains why telephone companies operating under price-cap regulation (with

[11] Gagnepain and Ivaldi (2002) stucturally estimate a model of the French Public Transit System and conclude that existing regulatory policies are far from optimal. In particular, cost-plus contracts reduce social welfare due to insufficient cost-reduction.

high-powered incentives) on average offer lower rates (Mathios and Rogers, 1989) and report higher profits (Ai and Sappington, 2002) than companies under cost-of-service regulation (with low-powered incentives).[12]

Discussion In the Laffont-Tirole model, the incentives for cost-reduction are maximized when prices are not distorted – i.e., when there is no reimbursement of cost overruns – so the natural monopoly bears the true social cost of its decisions. But with asymmetric information about the firm's true efficiency, such high-powered incentives imply large rents for efficient (low-cost) firms. In the constrained optimum, prices are distorted in order to reduce these rents. This trade-off is familiar from 1996 Laureate James Mirrlees' pioneering work on optimal taxation. In his model, incentives to earn income are maximized when marginal tax rates are zero. But positive marginal tax rates for agents with low earning ability make it possible to extract more revenue from high-ability agents, because it relaxes their incentive-compatibility constraints. Thus, the government optimally allows distortions for low-ability agents in order to reduce the information rents enjoyed by high-ability agents. A positive marginal tax rate for the highest ability agent would not relax any incentive-compatibility constraints, however – in the Mirrlees model, there should be "no distortion at the top". In the Laffont-Tirole model, no distortion at the top corresponds to a fixed-price contract for the most able ($\beta = \underline{\beta}$) type. All other types face distorted prices, i.e., they bear only some fraction of the production costs they incur.

A possible objection to the *o.s.m.* is that it is quite complex and requires hard-to-obtain information about the distribution of types. It is a valuable theoretical benchmark, but would such a complex scheme be adopted by real-world regulators? There are several responses to this kind of objection. First, one could use expert opinions to calibrate the range of uncertainty. Gasmi, Laffont and Sharkey (1997, 1999) show how engineering models can be used for this purpose. Moreover, there are plausible scenarios in which a large fraction of the social surplus generated by the *o.s.m.* can be attained by a simplified version of it. Rogerson (2003) considers a simplification where the menu consists of only two contracts: a cost-reimbursement contract (corresponding to $b(C^a) = 1$) and a fixed-price contract (corresponding to $b(C^a) = 0$). If the manager's utility is quadratic and types uniformly distributed, the simplified mechanism can always capture at least three quarters of the social surplus generated by the *o.s.m.* Gagnepain and Ivaldi (2002) estimate a structural econometric model of the French public-transit systems, and conclude that social welfare could be significantly raised if the operators were offered to choose between simple cost-reimbursement or fixed-price contracts.

Some U.S. regulators have begun offering regulated firms precisely this kind of choice, that of a low-powered scheme (cost-reimbursement) or a high-powered scheme (price-caps), and the theory provides a foundation for this (Laffont and Tirole, 2000, Chapter 2). The theory shows that more efficient firms should be given more high-powered incentives, and this is an important *qualitative* insight. Thus, even if regulators do not formally offer a menu of contracts, they may consider several options when negotiating with the

[12] Note that the theory advocates caution when interpreting this kind of empirical relationship. According to the *o.s.m.*, more efficient firms should choose more high-powered contracts, and the selection bias can create difficulties for econometric studies (see Gagnepain and Ivaldi, 2002).

regulated firm. A firm which thinks that it can produce at a low cost will argue in favor of (perhaps lobby for) a high-powered contract. Qualitatively, the negotiation may therefore lead to an outcome similar to that of a formal menu of contracts (as in the *o.s.m.*). The theory produces many other qualitative insights. For example, since it is the regulator's uncertainty about the firm's efficiency that distorts the firm's effort levels, any factor that reduces this uncertainty will reduce the distortions as well, i.e., incentives should become more high-powered. Two such factors are competition in an auction for the monopoly position, and benchmarking (where the firm's performance is compared to that of similar firms). Thus, all else being equal, auctions and benchmarking should lead to more high-powered incentive contracts (see Laffont and Tirole, 2000, Chapter 2).

Starting from their basic 1986 model, Laffont and Tirole came to enrich their theory and apply it to a series of public-policy issues. Their work, summarized in Laffont and Tirole (1993), launched a revival of the theory of regulation. More generally, it also inspired new theoretical work on public and private decisions under information asymmetries. Importantly, they imposed discipline on the research in this area. For example, we have seen that in the basic Laffont-Tirole model, the regulator makes transfers to the firm. Such transfers are a necessity in the case of procurement. But if the regulated firm sells its output directly to consumers, real-world regulators rarely have the legal power to tax or subsidize the firm. One response to this empirical observation could be to rule out transfers by assumption. But a key aspect of Laffont and Tirole's work was a reluctance to include such *ad hoc* assumptions. Instead, they wanted to fully specify the regulator's objectives and constraints, and calculate the optimum policy using all available instruments. Of course, there might be good reasons why transfers are rare – perhaps there is a danger of "regulatory capture". But Laffont and Tirole wanted to formalize these reasons, rather than simply *assume* that an instrument such as transfers is not used (see subsection 2.5 for their model of regulatory capture). This general perspective, which permeates almost all of Tirole's work, has raised the intellectual level on research in this area and added clarity as well as rigor to policy discussions.

So far, we have only considered the simplest possible case – a once-and-for-all procurement of an indivisible good by the government – to illustrate the basic model. We now consider some generalizations of this case.

2.3 Multi-Product Firms, Quality Concerns, Access Pricing and Network Interconnection

When the Laffont-Tirole model is applied to a multi-product firm, it sheds light on a number of important issues, such as concerns about quality and access pricing.

To set the stage, consider first a multi-product firm that sells its output directly to consumers, at regulated prices (following Laffont and Tirole, 1990a and 1993). Optimal pricing reflects two considerations. The first is the effect on consumer demand and the regulated firm's profits – this effect can be summarized by familiar Ramsey pricing formulas (except that the social cost of public funds λ replaces the shadow price of the firm's break-even constraint, just as in the optimal commodity-taxation literature; see Diamond and Mirrlees, 1971, Sandmo, 1974, and Hagen, 1979). The second consideration is the effect on the firm's incentives for cost reduction. However, as discussed in the previous subsection, if costs are observable then cost reimbursements can be designed to provide this incentive. Accordingly, Laffont and Tirole (1990a and 1993) show that if a certain separability condition holds,[13] then the incentive consideration does not influence the optimal pricing of the firm's output (price-incentive dichotomy). Goods should be priced according to familiar Ramsey pricing formulas, even though the cost function is endogenous and the government is able to subsidize financial shortfalls at the firm level, because distorting the price structure does not (under the separability condition) provide incentives for cost-reduction. With this simplest benchmark case in mind, we now consider some more complex cases of multi-product firms.

Quality concerns Formally, a firm with endogenous product quality is a special case of a multi-product firm, as we may consider low-quality and high-quality goods as different products. Therefore, if quality is verifiable and can be specified in a contract, the analysis is the same as for any multi-product firm, as discussed in the previous paragraph. The more interesting case occurs when quality is not verifiable. In this case, the regulator must create incentives for the regulated firm to provide the appropriate quality level – it cannot just be specified in a contract. Intuitively, high-powered schemes (such as fixed-price contracts) give the regulated firm an incentive to reduce quality in order to lower its costs, while low-powered incentive schemes (such as cost-plus or cost-of-service) encourage high quality because the cost is passed on to consumers and/or the government (see Kahn, 1988). Therefore, it seems intuitive that a quality-conscious regulator should choose a low-powered incentive scheme.

Laffont and Tirole (1993, Chapter 4) show that this intuition is correct for *experience goods*, where consumers cannot observe quality before purchase. An impatient manager who cares mainly about his current payoff can reduce quality without any immediate effect on the demand for the good. (The negative long-run effect, once consumers discover the low quality, is unimportant to the impatient manager). The regulator has only one instrument – the cost-reimbursement rule – with which to achieve the twin goals of high quality and low production cost. Since these goals are inherently in conflict, a trade-off arises: a high-powered incentive scheme results in low quality at low cost. Thus, for experience goods the intuitive argument is correct: a high concern for quality makes low-powered incentive schemes optimal. However, the intuitive argument is not correct for *search goods*, where consumers observe quality before purchase. In this case, the volume of sales is a quality index (since high quality implies high demand). The incentive to produce high quality can then be provided by rewarding the firm based on its volume of sales, while the incentive for cost reduction is again provided by the cost-reimbursement rule as discussed in subsection 2.2. For search goods, quality concerns should thus not necessarily shape the power of the cost-reimbursement rule.[14]

[13] An example of an aggregate cost function that satisfies the separability assumption is $C = C(\beta - e, q_1, q_2, ..., q_n)$, where β and e are defined as in subsection 2.2 and q_i denotes the output of good i. Using an engineering model, Gasmi, Laffont and Sharkey (1997) show that the separability condition is (approximately) satisfied for local telecommunications.

[14] There may however be an indirect effect. If a greater concern for quality causes the optimal quantity to increase, then this increases the marginal social benefit of cost-reducing efforts. To encourage more cost reduction, incentives should actually become more high-powered.

Access pricing and network interconnection Many regulated firms operate in a competitive environment. In addition to the usual considerations involving the regulated firm and its customers, the regulator must then also take into account how regulation affects other (typically unregulated) firms. An important example is *access pricing* – the terms on which a regulated incumbent should be required to supply inputs to downstream competitors. For instance, to compete for customers, rival firms might need access to a local network controlled by a large incumbent telephone company. The liberalization of industries dominated by vertically-integrated incumbents – such as telecommunications and electricity – made access pricing a hot topic in regulatory economics and policy. Further work by Laffont and Tirole (1990c, 1993, 1994) clarified the optimal regulation of access prices.

Formally, access pricing is another case of a regulated multi-product firm, where some of its products are sold to other firms. Suppose the regulated firm produces n goods. One of these – say good 1 – is used as an input by a competitive fringe of small and price-taking firms. The competitive fringe produces an output – say good $n+1$ – that competes with another product of the regulated firm – say good n. Disregarding incentives, the key insight is that goods 1 and n are substitutes. An increase in p_n (the price of the n^{th} good) increases the demand for the $n+1^{\text{st}}$ good, supplied by the competitive fringe, which in turn increases the demand for the input, good 1. This insight allows demand elasticities to be computed, and the optimal access price p_1 is given by a familiar-looking Ramsey-pricing formula.

In general, incentives cannot be disregarded, however. To set a fair access price, the regulator may need the regulated firm to reveal information about its cost function. The firm may be tempted to exaggerate the cost of supplying the input to its competitors in order to raise the access price and, perhaps, "foreclose" the downstream market (eliminate the competition). Laffont and Tirole (1993, Chapter 5) distinguish between two cases that entail quite different conclusions.

The first is a *common network*. In this case, the competitors use the same technology (the existing network) as the regulated firm to transform the input (good 1) into the consumption good (goods n and $n+1$). Therefore, if the manager of the regulated firm claims that the cost of giving access to competitors is high, he is also saying that the cost of producing good n is high. The regulator will then restrict the output of good n, and this mitigates the manager's incentive to lie about its cost of giving access.

The second, more difficult, case is *network expansion*. Here, the regulated firm can supply good n to the final consumer using its existing network, but giving access to competitors requires new facilities or interconnections. The regulated firm can then exaggerate the cost of giving access without also making a case against the production of good n. Now the regulator's constrained optimum will likely involve higher access prices, and less competition, than the first-best (full-information) outcome. Moreover, since a firm with high-powered incentives can gain more from increased access prices, low-powered incentives may be optimal.

As we shall see in Sections 4 and 5, concerns about anti-competitive foreclosure are central to the legal treatment of vertical restraints and to the regulation of access prices in network industries, and we thus discuss these concerns in those sections.

2.4 Contract Dynamics, Commitment Problems and Renegotiation

In practice, regulation is seldom once-and-for-all, but rather an activity that takes place over an extended period. The regulator may then be unable to commit to a regulatory policy over the relevant time span.[15] This causes two kinds of problems. The first is that the regulated firm may have insufficient incentives to make long-run investments. Suppose the firm can make a sunk-cost investment in a technology which will generate future cost savings. If the firm invests and its costs fall, the regulator may be tempted to expropriate the investment by reducing the transfer to the firm (or tighten its price cap). If the firm anticipates this kind of hold-up problem then it may prefer not to invest. This problem is the largest when long-run investments are essential, as in the electricity and telecommunications industries.[16] Tirole (1986b) provided a formal model of underinvestment in the context of government procurement under asymmetric information.

The second kind of commitment problem is studied by Laffont and Tirole (1988a, 1990b). It is more subtle than the hold-up problem, and depends on the existence of asymmetric information. To understand this problem, suppose the one-period Laffont-Tirole model described in subsection 2.2 is repeated twice. Thus, in each of two periods the government wants to procure the public good.[17] The firm's type (efficiency parameter β) is the same in both periods, and is unobserved by the regulator. If the regulator could credibly commit to a long-run (two-period) contract then it would be optimal to offer the *o.s.m.* in *both* periods (see Laffont and Tirole, 1993, Chapter 1). Thus, the optimal two-period outcome would simply implement the static optimum twice. This is the *perfect commitment outcome.*

But what if the regulator is unable to make credible long-run commitments? Laffont and Tirole analyzed this problem under different assumptions about the regulator's commitment power.[18] Laffont and Tirole (1988a) assumed the regulator cannot make any commitments whatsoever, so long-run contracts are simply ruled out. Laffont and Tirole (1990b) introduced a limited form of commitment: the regulator can write a long-run contract, and can commit not to *unilaterally* deviate from the contract, but he cannot commit not to renegotiate the contract if the regulated firm agrees to do so (i.e., if a

[15] In practice, regulatory policies are reviewed and revised periodically: in rate-of-return regulation the permitted rate-of-return is subject to adjustment, in price-cap regulation the maximum price is adjusted, etc. When the policies are reviewed, the regulator typically has some discretion. Even if a long-run contract exists, it will typically be quite incomplete, and this gives rise to the same kind of commitment problem as in the absence of long-run contracts. Laffont and Tirole (1993, Chapter 16) provide a different justification for the lack of long-term commitments, namely changing administrations.

[16] See Laffont and Tirole (2000) for an analysis of regulation and investment in the telecommunications industry.

[17] We abstract from the hold-up problem by assuming there are no long-run investments.

[18] Laffont and Tirole's work on dynamic regulation is somewhat different from the bulk of their work in that they did not use mechanism-design theory. A fundamental result of this theory, the *revelation principle*, states that maximum social welfare can be achieved by a revelation mechanism. Laffont and Tirole (1986) used the revelation principle to find the *o.s.m.*, but they did not use it in their later work on dynamic contracting. (For a general statement of the revelation principle, see Myerson, 1991, Section 6.9. To capture a lack of commitment, the regulator could be considered a player subject to moral-hazard constraints.)

Pareto-improvement exists).[19] We now discuss these models in turn.

Short-run contracting under asymmetric information Following Laffont and Tirole (1988a), suppose the regulator is unable to write any long-run contract with the regulated firm, but instead has to govern the relationship by a sequence of short-run (one-period) contracts. This gives rise to a *ratchet effect*, which is well-known from the literature on central planning (Weitzman, 1976). If an agent works hard and shows a good result, the principal may demand even better results in the future; anticipating this, the agent has little incentive to work hard in the first place. Restricting their analysis to linear contracts, Freixas, Guesnerie and Tirole (1985) provided the first formal analysis of optimal short-run contracts in the wake of such ratchet effects. They showed how the principal might initially sacrifice short-run efficiency to induce more information revelation from the agent.

Laffont and Tirole (1988a) considered optimal short-run contracting in the two-period version of the Laffont and Tirole (1986) model, without imposing any functional-form assumptions. Recall that the perfect commitment outcome would be to offer the *o.s.m.* in both periods, but this outcome requires a credible commitment to a long-run contract. To see that it cannot be implemented through a sequence of short-run contracts, recall that the manager's type is the same in both periods.[20] Now suppose the regulator offers the *o.s.m.* in period 1, and the firm self-selects thereby revealing its type (property S1 of the *o.s.m.*).[21] In period 2, the regulator no longer faces asymmetric information, and so prefers to offer a contract which induces first-best effort $e = e^*$ and expropriates the rent of the firm, $U = 0$. Anticipating this outcome, the firm is unwilling to reveal its type in period 1. Indeed, Laffont and Tirole (1988a) proved a *no-separation result*: with short-run contracting, *no* period-1 mechanism can induce full revelation of types.[22] There will always be some degree of *pooling*, so after period 1 the regulator will in general not know the firm's true type. Intuitively, the ratchet effect implies that information unfolds slowly, as the manager tries to protect his information rents by not revealing his true type.

Characterizing the set of equilibria in the two-period model is quite complex. Technically, the problem arises because the incentive-compatibility constraints can bind in both directions, not just downwards as in the static model. That is, the regulator has to worry not only about low-cost (low β) types pretending to be high-cost (high β), but also about high-cost types pretending to be low-cost. The latter concern is due to the fact that high β types may "take the money and run". To encourage low β types to self-select, the regulator must offer them a large payment in period 1, because low β types expect that,

[19] An alternative model of regulation with limited commitment was developed by Baron and Besanko (1987).

[20] More generally, the arguments require a positive correlation between period 1 and period 2.

[21] Recall that the optimal mechanism for the one-period Laffont-Tirole model described in subsection 2.2, referred to as the *o.s.m.*, had three key properties: (S1) self-selection, (S2) $e < e^*$ for all types except $\underline{\beta}$, and (S3) $U > 0$ for all types except $\overline{\beta}$.

[22] Here is a sketch of a proof by contradiction. Suppose type $\hat{\beta}$ reveals itself in period 1, so in period 2 it gets no rent. Therefore it chooses the first-period contract that maximizes its first-period payoff. By imitating type $\beta' > \hat{\beta}$, in period 1 the firm would not lose anything to the first order (since it was choosing its best contract). But it would gain a second period rent proportional to $\beta' - \hat{\beta}$, so it would be made better off overall, a contradiction.

if they reveal themselves, the regulator will extract their rents in period 2. Now the high β type may be tempted to pretend to have low β, take the high payment in period 1, but then reject the period-2 contract and exit the industry (take the money and run).

Thus, Laffont and Tirole show that the commitment problems can be quite complex. The main point is that – as already suggested by Freixas, Guesnerie and Tirole (1985) – the firm will be reluctant to reveal that its costs are low, fearing that its information rents will be expropriated (the ratchet effect). Therefore, as suggested by the no-separation result, the regulator must refrain from getting "too much information". These important insights have become recurrent themes in subsequent research on dynamic contractual relationships.

In practice, a regulator may employ various strategies to remain ignorant about the firm's cost. For example, the regulator may try to commit to infrequent reviews of a price cap.[23] If this commitment is credible, the firm will have a strong incentive to minimize its production cost. However, if the commitment is not credible, the firm expects that any cost reductions will quickly trigger a tighter price cap, and the incentives for cost-minimization vanish.

Long-run renegotiated contracts Now suppose that the regulator and the firm can write a long-run contract, and that each party can credibly commit not to unilaterally deviate from the contract terms. Can the perfect-commitment outcome, where the firm receives the *o.s.m.* in both periods, be implemented in this case? Laffont and Tirole (1990b) suggested that the answer may be no, as the regulator and the firm may *jointly* benefit from renegotiation. Recall property S1 of the *o.s.m.* – the manager reveals his true type – and property S2 – if his type is $\beta > \underline{\beta}$ then his effort is less than first-best ($e < e^*$). If the manager reveals his type $\beta > \underline{\beta}$ in period 1 then both parties know that a Pareto-improvement is possible in period 2, because the *o.s.m.* outcome is not first-best. So the perfect commitment outcome is not renegotiation-proof. Of course, anticipating that the contract will be renegotiated in period 2 changes the manager's incentives in period 1, and this makes the overall outcome worse than under perfect commitment. Thus, the regulator would like to commit, if possible, to never renegotiating the initial contract. Unless such a commitment is possible, the commitment solution cannot be implemented even when long-run contracts can be written.[24]

A mechanism that is not renegotiated in equilibrium is called *renegotiation-proof,* a concept that derives from Dewatripont (1989). Hart and Tirole (1988) applied this concept to a model of dynamic contracting between a buyer and a seller when the buyer's type (his valuation of the good) is private information. They compared period-by-period renting of a durable good with outright selling, with or without long-term (renegotiable) contracts. With only short-run contracting, equilibrium of the rental model is similar to Laffont and Tirole's (1988a) equilibrium, with pooling caused by a ratcheting effect. But with a renegotiable long-term contract, the rental model has the same equilibrium as the sale model. Moreover, they demonstrated a close parallel to the problem facing Coase's

[23] For a discussion of optimal regulatory lags, see Armstrong, Rees and Vickers (1991).

[24] In theory, a commitment not to renegotiate might be accomplished by contracting with a third party, who is promised a large payment if the regulator renegotiates the original contract. However, entering into such third-party agreements may not be possible for institutional reasons, so it is reasonable to assume that the regulator cannot commit not to renegotiate.

(1972) durable-goods monopolist: when it is impossible to commit not to renegotiate long-run contracts, the equilibrium has Coasean features (a declining price path). We shall return to this theme in Section 4.

Laffont and Tirole (1990b) applied a similar analysis to renegotiable long-run contracts in the twice-repeated Laffont-Tirole (1986) model. Since long-run contracts are feasible, the regulator can commit to give the firm rents in period 2. (Pareto-improving renegotiation would not eliminate this rent.) Therefore, take-the-money-and-run is not a problem, and the incentive-compatibility constraints only bind downwards as in the static model. In this sense, the case of renegotiation-proof long-run contracts is more straightforward than the case of short-run contracting. With renegotiation-proof long-run contracts, full separation of types is feasible, but it is not optimal for the regulator (see Laffont and Tirole, 1993, Chapter 10). As in the case of short-run contracting, the regulator's renegotiation-proof optimum involves pooling of types, i.e., the regulator must refrain from getting "too much" information.[25]

Fully characterizing the regulator's renegotiation-proof optimum with a continuum of types is technically challenging. However, the solution can be readily explained for the case of two types, $\overline{\beta}$ and $\underline{\beta}$ with $\underline{\beta} < \overline{\beta}$. If the regulator and the manager are sufficiently patient (period-2 payoffs are sufficiently valuable), then separating the two types in period 1 is never optimal. In period 1, the regulator offers the firm's manager a choice between a long-run fixed-price contract that induces first-best effort in both periods, and a short-run contract that does not induce first-best effort. The high-cost type ($\beta = \overline{\beta}$) chooses the short-run contract for sure, but the low-cost type ($\beta = \underline{\beta}$) randomizes between the two contracts. The short-term contract induces pooling, i.e., both types produce at the same cost. Thus, after period 1, the regulator will never know for sure that the manager is the high-cost type (as the low-cost type chooses the short-run contract with some probability). If the firm chooses the short-term contract, in period 2 the regulator makes an offer which is conditionally optimal given his posterior beliefs. Since the long-run contract induces the first-best effort in period 2, there is no scope for renegotiation. Moreover, similar to the case of short-run contracting, pooling is more likely the more patient the regulator and the firm are.

The general lesson of Laffont and Tirole (1990b) is thus quite similar to that of Laffont and Tirole (1988a). When the regulator cannot commit to a long-run contract, he will be tempted to take advantage of information revealed by the firm. To avoid succumbing to this temptation, the regulator must refrain from becoming too well-informed. In the constrained optimum, the more important the future payoffs, the less well informed he will be. These insights hold whether or not long-run contracts can be written, as long as renegotiation is possible.

2.5 Institution Design: Regulatory Capture or Motivated Agents?

Game-theoretic modelling requires explicit assumptions about human behavior. Tirole has studied regulatory capture under the assumption that regulators obey the standard selfishness axiom and thus maximize their own private welfare (rather than social wel-

[25] The main difference is that with long-run renegotiation proof contracts, separation of types is feasible but not optimal. With short-run contracts, separation is not even feasible (the "no separation" result).

fare). However, he has recently found it necessary to modify this axiom, allowing some individuals to have more pro-social motives than just lining their own pockets. This subsection describes Tirole's most important results on regulatory capture and motivated agents, respectively.

Regulatory capture In recent decades, economists have become more attuned to the idea that sector-specific regulation is a perilous task which, at worst, can be captured by the regulated industry. Simply put, regulation may end up benefitting producers rather than consumers (Stigler, 1971). A growing body of empirical studies backs this up by documenting various regulatory dysfunctions (Dal Bó, 2006). In fact, regulatory capture is an example of a more general phenomenon: collusion in hierarchical organizations. The first formal game-theoretic analysis of this was Tirole's (1986a) model of a three-tier structure consisting of a principal, a supervisor and an agent. We discuss this model and its importance in Section 6.4.

Laffont and Tirole (1991) adapted the three-tier structure to the problem of regulatory capture. Suppose a higher authority designs a framework for regulation and, within this framework, the regulatory agency interacts with the regulated firm. Suppose further that the regulatory agency occasionally obtains verifiable information about the firm's cost conditions: for simplicity, the firm's cost-type is either high $\beta = \overline{\beta}$ or low $\beta = \underline{\beta} < \overline{\beta}$. While such information is potentially useful, Laffont and Tirole (1991) argued that the agency cannot be relied upon to internalize the higher authority's objectives. This is not a problem if the agency observes high-cost conditions, $\beta = \overline{\beta}$, as the firm's manager does not mind revealing that his task is difficult. If, however, the agency learns that cost conditions are favorable, $\beta = \underline{\beta}$, the firm does not want this information to be known.

Because of this conflict of interest, there is room for collusion between the agency and the firm. In effect, the firm's manager may bribe the agency to suppress information that may hurt the firm.[26] In the model, the maximum bribe the firm is willing to pay depends on the prospective information rent it receives if its type is not revealed. If this rent is large, the firm has a large incentive to bribe the regulatory agency, and the higher authority will find it difficult or costly to prevent collusion. One way for the higher authority to reduce the threat of collusion is therefore to reduce the information rent.[27] Recall that in the Laffont-Tirole (1986) model, reducing information rents requires a greater distortion of the high-cost type's effort (by giving it something akin to a cost-plus contract). This verifies the insight, first put forward by Tirole (1986a), that the threat of collusion makes low-powered incentive contracts more desirable. Again, we find that low-powered incentives do not necessarily indicate a poor regulatory design. It may instead be an optimal response to a threat of regulatory capture.

[26] The term "bribe" is used as a short-hand for any compensation or favor. For example, the regulated firm may offer the regulator a lucrative job.

[27] Another (costly) way to prevent collusion is to increase the incentives for the regulatory agency to reveal detrimental information. Suppose the higher authority pays s to the regulatory agency whenever it reveals that $\beta = \underline{\beta}$. Then the agency will be captured (will *not* reveal that $\beta = \underline{\beta}$) if the firm offers a bribe of at least s. If the firm is willing to pay a large bribe to protect a large information rent, then the higher authority can only prevent collusion by choosing s very large. This is costly because s must be financed by distortionary taxation.

Motivated agents So far, we have only discussed models which assume that all agents are purely selfish. While this assumption simplifies the analysis, human nature may be less dismal. Some agents may want to promote social welfare or more generally "do the right thing". As Bénabou and Tirole (2011) demonstrate, personal values as well as desire for social esteem may sometimes change optimal incentives quite strongly, and this is an important research frontier.

One intriguing question is how to regulate agents if the principal is uncertain about the agent's motives. This problem is perhaps greatest when the agent takes decisions not about how hard to work (as in the simple regulation model we have considered so far) but about some other action, the consequences of which appear only in the longer run. In this case, a selfish agent should ideally be tightly controlled or strongly incentivized, as before, but a pro-socially motivated agent should ideally have a free reign.

In joint work with Eric Maskin, Tirole has argued that the regulation of politicians and other holders of high office (such as high-court judges) largely reflects a trade-off between containing conflicts of interest and allowing socially motivated experts sufficient leeway. In Maskin and Tirole (2004), the contract is an institution that specifies: (i) who gets to make what decisions, and (ii) procedures for inducing public decision makers (informed agents) to act in the interest of the broader population (less informed principals). Their central assumption is that the informed agents are concerned not only with material benefits or other private returns to power, but also with making socially beneficial decisions and thereby leaving a valuable "legacy".[28]

Since agents differ in the strength of their pro-social motives, power will sometimes be abused. Thus, the population will only leave extensive discretion to hired agents when the decisions either require a lot of expertise or when direct democracy is likely to entail undue exploitation of minorities. In these two cases, decisions may be delegated to long-serving experts ("judges"). At the other extreme, if the population believes that issues are straightforward and the majority's benefits are not outweighed by the minority's costs, it prefers direct democracy. In the intermediate case, where issues require expertise, but decisions can be evaluated relatively quickly, it will delegate decisions to agents operating within term-limits – politicians in a representative democracy.

3 Industrial Organization: Strategic Behavior in Imperfectly Competitive Industries

The field of Industrial Organization (IO) studies how markets function. The main emphasis is on how firms exercise their market power in imperfectly competitive markets, how they interact with other firms, the welfare implications of such behavior, and the justifications for government intervention. In the case of natural monopolies, the government may directly regulate the monopolist (as discussed in Section 2). However, many markets allow more than one firm to operate, and it may be in the public interest to promote competitive behavior in these industries (as will be further discussed in Section 4). Oligopoly theory provides a scientific foundation for such interventions.

[28] To be precise, it is assumed that the agent is an impure altruist who does not primarily get satisfaction from socially desirable outcomes, but from his own contribution to those outcomes.

After a brief historical background, subsections 3.2, 3.3 and 3.4 will discuss some of Jean Tirole's most noteworthy contributions to oligopoly theory.

3.1 Historical Background

In the first half of the 20th century, the industrial organization literature contained many detailed descriptions of specific oligopolistic industries, but with very little formal analysis. Except for a few deep and prescient contributions in the 19th century (notably Cournot 1838, Bertrand, 1883, and Edgeworth, 1897), the theoretical analysis of oligopoly before World War II was far from the modern standards of rigor and logical consistency. This classical theory certainly did not affect any empirical work – which at the time was mainly descriptive, with little formal statistical analysis, no attempts to estimate parameters of an underlying structure, and no serious attempts to uncover causal relationships.

In the 1950s, the work of Joe Bain (1951, 1956) propelled the so-called Structure-Conduct-Performance (SCP) paradigm. The basic idea was that industry conditions (the number of sellers, the production technology, and so forth) determine industry structure, which determines firm conduct (pricing, investment and so forth), which in turn determines industry performance. A typical study in this tradition would use cross-industry data to regress a performance measure – such as accounting price-cost margin – on a concentration measure – e.g., the Herfindahl Index, or the combined market share of the three largest firms. Prescriptions for government policies, particularly with regard to horizontal mergers, reflected the SCP paradigm and were largely based on these concentration measures.

In the 1960s and 1970s, the "Chicago School" (e.g., Demsetz, 1973) questioned the value of the cross-industry studies that formed the basis for the SCP paradigm. Different outcomes in different industries could be due to variables not included in these studies, so the fundamental problem was the interpretation of a correlation as a causal effect. Proponents of the SCP paradigm typically interpreted a positive relation between concentration and profitability across industries to mean that a higher concentration leads to higher industry profits. But an equally plausible interpretation is that highly efficient (and therefore profitable) firms drive inefficient rivals out of the industry, leading to higher concentration. These two interpretations have very different implications for public policy, but there was no way to distinguish between them based on the typical SCP study (see Schmalensee, 1986, for a critical discussion).

The Chicago School raised legitimate questions, but lacked the formal tools to analyze the strategic behavior of firms in imperfectly competitive industries. Formal modelling at the time was basically restricted to the two polar cases of perfect competition and monopoly. This did not allow a rigorous analysis of how the industry-specific conditions unearthed by empirical researchers would determine the performance of these industries. In the 1980s, the game-theory revolution in IO closed the circle by supplying the tools necessary to take these industry-specific conditions into account. Since then, game theory has become the dominant paradigm for the study of imperfect competition, providing a rigorous and flexible framework for building models of specific industries, which has facilitated empirical studies and welfare analysis. Subsections 3.2, 3.3 and 3.4 will describe some important advances made during this revolution. We focus on theoretical research, but we stress that the theoretical advances fundamentally affected the empirical IO literature as well (see, e.g., Sutton, 1991, 2007; Berry and Reiss, 2007; Doraszelski and Pakes, 2007).

We also do not attempt to provide a comprehensive survey of modern IO theory. Instead, we focus on the most important contributions by Tirole. A more complete description of the state of the art in IO theory as of the late 1980s can be found in his own influential textbook (Tirole, 1988). This book surveys the theory of monopoly behavior (e.g., price discrimination and vertical control), as well the main game-theoretic models of imperfectly competitive industries, including many major advancements that will not be discussed here. More than 25 years after its publication, Tirole's book remains an excellent introduction to the field and a standard reference. In fact, the book was always more than a textbook: it defined modern IO theory by organizing and synthesizing the main results of the game-theory revolution.

3.2 Strategic Investment and Short-Run Competition

To what extent can a dominant firm block entry into its industry, or otherwise manipulate the behavior of smaller rivals? Before the game-theory revolution, such questions had been analyzed by rather blunt methods. For example, one might postulate that other firms believe that entry will not cause an incumbent firm to change its output (the so-called Sylos-Labini postulate). To block entry, an incumbent should thus produce a quantity that would make entry unprofitable. However, there was no real justification for such postulates. Perhaps the incumbent's output level would be fixed in the short term, but why would it not eventually adjust its behavior in the wake of entry? Previous Economics Laureates Reinhard Selten (winner in 1994) and Thomas Schelling (winner in 2005) rigorously analyzed these kinds of questions in more general settings, introducing new concepts like *subgame-perfect equilibrium* and *credible commitments*. In the late 1970s, the time was ripe for incorporating these general ideas into IO. The 2001 Economics Laureate Michael Spence (1977, 1979) studied how incumbents (first-movers) could use strategic investments to manipulate the behavior of rivals (second-movers). But Dixit (1980) was the first to properly analyze this kind of problem using the concept of subgame-perfect equilibrium. His model was based on Spence (1977) but, unlike Spence, Dixit ruled out non-credible threats by considering Nash equilibria in the post-entry game.[29]

Credible commitments Game theory thus made it possible to carry out a rigorous analysis of strategic investments in physical capital, R&D, advertising and the like. Such investments have *commitment value* because they are irreversible and change payoff-relevant state variables. Quantity or price decisions typically have much less commitment value, because they are so much easier to reverse. This was made clear by Dixit (1980). However, contributions by Fudenberg and Tirole (1984) and Bulow, Geanakoplos and Klemperer (1985) revealed that an analysis of strategic investment is quite sensitive to the details of the market environment.

[29] Fudenberg and Tirole (1983) applied the concept of subgame-perfection to the Spence (1979) model. They found a continuum of "collusive" subgame-perfect equilibria, where firms refrain from investing because a unilateral deviation would lead to a continuation where each firm invests much more, lowering the profits of both firms.

We illustrate these findings in a simple example, based on Fudenberg and Tirole (1984). Consider an industry with an incumbent monopolist and a potential entrant. First, the incumbent moves: he makes a publicly observed investment denoted x; perhaps expanding productive capacity, or investing in R&D to lower production costs. Then, having observed the investment, the (potential) entrant moves: she decides whether or not to enter. Without entry, the incumbent enjoys monopoly profit $\pi^M(x)$. With entry, we have a competitive subgame: the incumbent and the entrant take actions (price or output decisions) denoted z_I and z_E, respectively. Assuming the incumbent's investment x does not *directly* influence the entrant's profits, the incumbent's and the entrant's profits in the competitive subgame are denoted $\pi^I(z_I, z_E, x)$ and $\pi^E(z_I, z_E)$, respectively. Importantly, x is a *credible commitment* which cannot be changed ex post. For example, if an incumbent expands productive capacity, he cannot undo this investment after entry.

In subgame perfect equilibrium, actions z_I and z_E in general depend on x. Formally, $z_I = z_I(x)$ and $z_E = z_E(x)$, where $z_I(x)$ maximizes $\pi^I(z_I, z_E(x), x)$ and $z_E(x)$ maximizes $\pi^E(z_I(x), z_E)$. The entrant will enter if she can make positive profit in the competitive subgame, i.e., if $\pi^E(z_I(x), z_E(x)) > 0$. Thus, if the incumbent decides to deter entry, he should choose $x = x_D^*$ which maximizes monopoly profit $\pi^M(x)$ subject to the constraint $\pi^E(z_I(x), z_E(x)) \leq 0$. But deterring entry is not necessarily the incumbent's best option. If he instead decides to accommodate entry, he should choose $x = x_A^*$ which maximizes his profit $\pi^I(z_I(x), z_E(x), x)$ in the competitive subgame. His best option is to deter entry if

$$\pi^M(x_D^*) > \pi^I(z_I(x_A^*), z_E(x_A^*), x_A^*).$$

This model can be used to rigorously analyze the conditions under which entry will be deterred.

Strategic interactions Fudenberg and Tirole's (1984) main insight was that the incumbent's optimal strategy depends on several aspects of the environment, such as whether the investment makes the incumbent firm "tougher" or "softer" and whether short-run competition involves *strategic substitutes* or *strategic complements* (in the terminology of Bulow, Geanakoplos and Klemperer, 1985). Suppose short-run competition is in prices: then z_I and z_E are the prices set by the incumbent and the entrant in the competitive subgame. For almost all common specifications of demand conditions, prices are strategic complements: if one firm lowers its price then the other firm's best response is to lower its price as well. Furthermore, suppose the incumbent's investment x reduces his marginal production cost. This investment makes him tougher – i.e., he will tend to set a low price in the competitive subgame, which (by strategic complements) will induce the entrant to set a low price as well. The more the incumbent invests, the more fierce the competition in the competitive subgame, which tends to lower both firms' profits. Therefore, the optimal way to accommodate entry is for the incumbent to *under-invest*: he makes sure his marginal cost is quite high in order to soften the price competition. If the incumbent instead wants to maintain his monopoly and deter entry, he may have to *over-invest*: he makes sure his marginal cost is very low so that the entrant cannot profitably enter.[30]

[30] Fudenberg and Tirole (1984) formally defined the concepts of under- and over-investment. Here, we simply highlight the intuition.

These conclusions relied on the assumptions that the investment makes the incumbent tougher and short-run competition is in prices. The conclusions are quite different if the investment makes the incumbent softer, or if short-run competition is in quantities. In effect, Fudenberg and Tirole (1984) classified the environments where particular business strategies would be optimal. This became a recurring theme of the game-theory revolution in IO: rather than proving sweeping results that apply to any industry, certain characteristics of an industry dictate a certain outcome. Game theory thus gave empirical IO a framework for organizing the data and understanding the diverse behavior of real-world markets. This way, the field could return to the theme of the first half of the century – industries are quite different from each other – but on a much more solid footing.

3.3 Long-Run Competition and Markov Perfection

The early game-theoretic IO literature, such as Dixit (1980) and Fudenberg and Tirole (1984), relied on simple two-stage models, where firms make irreversible decisions in stage 1, and short-run competition occurs in stage 2. The more recent IO literature has emphasized dynamic models with many periods – indeed, with a game that does not end on any fixed date. However, such infinite-horizon games typically allow for a plethora of subgame-perfect equilibria. This is because choices in one period may depend on the whole history of play, giving rise to "bootstrap" equilibria that would disappear if the game were truncated after a finite number of periods. These bootstrap equilibria sometimes require an unrealistically high degree of shared memory and coordination. For many questions that IO researchers are interested in, such as the commitment value of irreversible decisions, it is useful to refine the notion of subgame-perfect equilibrium to eliminate these bootstrap features.

Markov Perfect Equilibrium: an example Together with 2007 Laureate Eric Maskin, Jean Tirole introduced such a refinement, the *Markov Perfect Equilibrium* (MPE), and showed that it could be profitably used in a number of applications in IO (Maskin and Tirole, 1987, 1988a, 1988b).[31] In MPE, choices in each period only depend on payoff-relevant state variables, i.e., variables entering directly into payoff functions (e.g., by influencing demand or cost conditions). This restriction makes models of long-run competition more tractable and the notion of MPE has become very influential, especially in empirical work (see further below).

Although the concept of MPE is quite general, the early Maskin-Tirole papers focussed on games with *alternating moves.* Maskin and Tirole (1988a) considered quantity-competition. Suppose two firms compete in the market. At each time t^*, firm i wants to maximize the discounted sum of its future profits

$$\sum_{t=t^*}^{\infty} \delta^{t-t^*} \pi_i^t,$$

[31] An early precursor to the concept of MPE exists in 2012 Laureate Lloyd Shapley's work on stochastic games (Shapley, 1953).

where δ is the discount factor and π_i^t is its profit in period t. To produce a strictly positive output in any period requires paying a fixed cost $F > 0$. A firm that incurs the fixed cost has entered the industry in this period. Suppose the fixed cost is large enough that only one firm, and not two firms, can profitably operate in the market.

In odd-numbered periods t, firm 1 chooses its output level q_1^t, which remains unchanged until period $t+2$. Thus, output choice is irreversible and the firm is committed to it for two periods. Similarly, firm 2 chooses its output q_2^t in even-numbered periods. The Markov assumption is that a firm's strategy depends only on the payoff-relevant state – here, this is the output chosen by the other firm in the previous period. Thus, firm j's decision in period $t-1$ determines the state firm i must react to in period t. Formally, firm i's strategy is a dynamic reaction function R_i, where $q_i^t = R_i(q_j^{t-1})$ is firm i's output in period t when firm j chose q_j^{t-1} in period $t-1$.

An MPE is a pair of reaction functions forming a subgame-perfect equilibrium, and Maskin and Tirole showed that there exists a unique symmetric MPE in the quantity-competition model. This equilibrium has a *deterrence output level* $\bar{q}$ – i.e., an output level above which the other firm is deterred from entering and below which the other enters with positive probability. After an initial transitory period, if a firm operates at all, it does so at or above the deterrence level. Thus, in equilibrium a firm either drops out of the market forever, or induces the other firm to do so. This model formalizes the commitment value of irreversible decisions in a way that is reminiscent of the earlier two-period models of entry-deterrence (Dixit, 1980, Fudenberg and Tirole, 1984), but in an infinite-horizon dynamic model.

When the discount factor δ is large enough, then $\bar{q}$ is above monopoly output: to deter its rival from entering, a firm must produce above the profit-maximizing level of a single firm. Even though only one firm is active, its price is lower than the monopoly price, just as in the older literature on limit pricing (e.g., Kamien and Schwartz, 1971). In fact, as δ tends to 1, the incumbent's output approaches the level that would result from perfect competition, just as in the literature on contestable markets (Baumol, Panzar, and Willig, 1982).

Maskin and Tirole (1988b) instead considered price competition with alternating moves. In contrast to the uniqueness result under quantity competition, the price-competition model has multiple equilibria. Specifically, there exist both "kinked-demand-curve" equilibria and "Edgeworth-cycle" equilibria. In the former, prices eventually settle down to a focal price, which is sustained by each firm's fear that, if it undercuts, the other firms will do so too. Charging more than the focal price is not profitable because the other firm will not follow. The Edgeworth cycle is an asymmetric cyclical pricing pattern, where price wars are followed by sharp price increases. During price wars, firms successively undercut each other to increase their market share, until the war has become too costly and one firm increases its price. The other firm then follows suit and raises its price, and then price cutting starts again.

Empirical relevance and applications The notions of kinked demand curves and Edgeworth price cycles have a long history (Edgeworth, 1925, Hall and Hitch, 1939, Sweezy, 1939), but the treatments were mainly informal. Similarly, the literature on contestable markets contains heuristic justifications for why a monopolist under threat of entry may behave (almost) like a perfectly competitive firm. Maskin and Tirole showed how all these notions could be rigorously derived from an equilibrium model. This helps us understand how imperfectly competitive industries might behave over time, and can help identify patterns in empirical data. For example, several empirical studies have found Edgeworth price cycles in retail gasoline markets (Noël, 2007, and Zimmerman, Yun and Taylor, 2013).

Since the early papers of Maskin and Tirole, the MPE concept has been applied to many dynamic IO models and has stimulated a large amount of empirical research, which has led to a better understanding of oligopoly dynamics.[32] In fact, the importance of MPE extends far beyond the study of IO. The refinement is routinely applied within macroeconomics, political economics, development economics, and other fields. In general, MPE dynamics can be quite complex and analytic results hard to obtain. But empirical researchers interested in a particular industry can estimate the parameters of their model, use those estimates to compute the industry equilibrium, and then numerically study the dynamic evolution of the industry. Indeed, computational methods for finding MPEs of dynamic IO games have become increasingly popular in the new literature that pursues structural estimation for specific markets. Much of this literature builds on the framework developed by Pakes and McGuire (1994) and Ericson and Pakes (1995).

3.4 Innovation and Adoption of New Technologies

Economic theory increasingly emphasizes how new technologies drive economic growth and deliver the benefits of competition to consumers. Within private firms, researchers are given monetary incentives to develop these new technologies, and the patents become the property of their employers.[33] IO theorists want to understand how investments in R&D depend on market structure, how the benefits from R&D are allocated among firms and consumers, and if there are reasons for government intervention.

Patent races R&D competition among firms is often portrayed as a race to obtain a patent, where a firm that spends more resources increases its chances of winning.[34] The firm that has invested the most in R&D in the past is the leader in that race – i.e., it has the highest probability of winning. Thus, past (irreversible) investments can create a first-mover advantage and a follower may not even want to participate in a race he is unlikely to win. This logic was formalized by Fudenberg, Gilbert, Stiglitz and Tirole (1983). They showed that if past R&D expenditures are perfectly observed, and if the patent is a one-time discovery (there are no intermediate discoveries), then the follower will indeed be deterred from entering the race. However, if past R&D expenditures are

[32] The literature inspired by Maskin and Tirole's early papers typically drops some of their stringent assumptions, such as alternating moves. As Maskin and Tirole (2001) show, the concept of MPE can be defined naturally and consistently in a large class of dynamic games.

[33] An interesting question is how the contracts between employers and innovators should best be formulated; for an early contribution to this literature, see Aghion and Tirole (1994). We leave this question aside here.

[34] Important early contributions to the theory of patent races include Dasgupta and Stiglitz (1980), Lee and Wilde (1980), Loury (1979) and Reinganum (1982).

not perfectly observed, the more plausible case, the follower may be able to leapfrog the leader, and the competition to obtain the patent becomes very stiff (unless the leader is very far ahead, in which case the follower gives up). Similarly, competition is stiff if intermediate discoveries can be made – in this case, the follower can leapfrog the leader by making the first intermediate discovery.

The results of Fudenberg et al. (1983) suggest that a patent race will be very intense, with high R&D expenditures from both firms, when the race is close. Thus, at least under some conditions, intense competition will stimulate R&D efforts. If the leader is too far ahead, the follower gives up, and the leader reduces his R&D expenditures, as he is no longer challenged.

Open-source software The literature on patent races assumes that R&D investments are driven by the traditional profit-motive. However, economists are increasingly realizing that not all new technologies originate in this way. An important example is *Open Source Software* (OSS), where programmers at many different locations and organizations share code to develop new software. This process was important in the development of the Internet, contributing such software as TCP/IP, BIND, Perl, Sendmail, Linux, Mozilla and Apache. What initially baffled economists was that OSS developers did not seem to benefit financially from their efforts. OSS is, in effect, a public good, which raises the question why OSS programmers contribute voluntarily, without pay, to the public good.

Lerner and Tirole (2002) argued that economic theory may, in fact, be able to answer this question. Their main hypothesis is that software developers have career concerns. Contributing to the OSS may be a credible signal of one's programming ability, which may lead to job offers, shares in commercial open source-based companies, or access to the venture-capital market.[35] Drawing on a previous literature on career concerns (e.g., Holmstrom, 1982), they argue that the signaling motive is stronger the more visible is performance, the higher the impact of effort on performance, and the more informative performance is about talent. They find support for the signaling motive in four case studies (Apache, Linux, Perl and Sendmail). Subsequent research also found support for Lerner and Tirole's (2002) signaling theory, at least for some OSS projects (e.g., Hann, Roberts and Slaughter, 2013, for Apache). However, programmers seem to contribute to OSS for a variety of reasons, perhaps including altruism. A satisfactory explanation of OSS development may require a mixture of signaling theory and insights, like those of 2009 Economics Laureate Elinor Ostrom, into how cooperative behavior can be supported by norms and other social mechanisms (O'Mahony, 2003).

Adoption of new technologies When a new technology first becomes available it may be quite costly to adopt. Over time, adoption becomes cheaper, but waiting too long to adopt puts a firm at a competitive disadvantage. Thus, the adoption of a technology becomes a game of timing. Fudenberg and Tirole (1985) showed that the subgame-perfect equilibria of such games can be highly inefficient.

[35] Lerner and Tirole (2002) also considered a complementary hypothesis of "ego gratification": contributing to the OSS leads to peer recognition which is inherently valuable. They consider that this hypothesis, as well as career concerns, falls under the heading of signaling.

Tirole (1988) illustrates this inefficiency by a simple example. Consider a price-setting (Bertrand) duopoly where the two firms initially have per-unit production cost $\bar{c}$, but a new technology reduces the cost to $\underline{c} < \bar{c}$. The innovation is non-drastic, in the sense that a monopolist with production cost $\underline{c}$ would still charge a price above $\bar{c}$. Suppose the new technology is not patented; at any time t, each firm is free to adopt it at a cost $C(t) > 0$. At time 0, the adoption cost $C(0)$ is prohibitively high, but the cost decreases over time: $C'(t) < 0$. Before the new technology is adopted, both firms set the price $p = \bar{c}$ and make zero profit. In subgame-perfect equilibrium only one firm adopts the new technology at a particular time t^*; after that, it supplies the whole market at the old price $p = \bar{c}$.[36] It earns a monopoly rent, because its production cost is only $\underline{c} < p$. The other firm will not adopt, because subsequent Bertrand competition would yield zero profit. The key point is that the equilibrium adoption time t^* is such that the present value of the future monopoly rent equals the adoption cost $C(t^*)$. If this were not the case, preemption would be worthwhile.

This equilibrium is highly inefficient: in fact, there are no social gains from the new technology. The monopoly rents are completely dissipated by the adoption cost, and the consumers gain nothing, because the price remains at $\bar{c}$. This extreme result reflects the special assumptions, but the intuition is clear: intense competition for monopoly rents tends to dissipate the gains from new technologies. Thus, while highly competitive markets may indeed bring about adoption of new technologies, this does not necessarily bring about great social benefits. While this may seem counter-intuitive, it actually formalizes an old insight (see Posner, 1975): competition for monopoly rents may cause these rents to be dissipated in a socially wasteful way.

Co-marketing, patent pools, and standard-essential patents To what extent should sellers of different products be allowed to engage in joint marketing and pricing? Standard economic logic suggests the following: On the one hand, it is desirable to allow sellers of complementary products to cooperate, as this will facilitate reasonably priced bundles. On the other hand, it is undesirable to allow sellers of substitute products to cooperate, as this may facilitate collusion on higher prices.

However, as Lerner and Tirole (2004) show, this argument has limited value because it may be difficult to know whether products are substitutes or complements. Indeed, it may depend on current prices. For example, consider the demand for two indivisible products. Suppose a customer of type $\theta > 0$ values the products at $U(n) = (\theta + V(n))I_n$, where n is the number of products that the customer purchases, I is an indicator variable that takes the value 1 if $n \geq 1$ and 0 otherwise, and $V(2) < V(1)/2$. If both prices are below $V(2) - V(1)$, the customer will either buy both products or none. Hence, if one price goes up a little (but stays below $V(2) - V(1)$), demand for the other product will either stay constant or fall, depending on the size of θ – the products are complements. On the other hand, if both prices are above $V(2) - V(1)$, the customer will either buy the cheapest product or none – the products are substitutes.

In such circumstances, should policy-makers let firms cooperate on how to price product bundles, or should they insist on price competition where each firm sets its own price?

[36]With a non-drastic innovation, this is the standard "textbook" outcome of Bertrand competition with asymmetric firms.

Lerner and Tirole (2004) propose the following intermediate policy: allow firms to collaborate on the pricing of bundles, but at the same time insist that any firm is always free to price its component as a stand-alone offer. The point is that firms will not desire to make such stand-alone offers when the optimal bundle price entails lower average prices than competition, but will be tempted to do so when the bundling entails higher prices than competition. This policy does not require the authorities to have any knowledge about demand conditions. Thus, the analysis produces a strikingly simple and robust piece of policy advice: allow collaboration with respect to bundling, but do not allow firms to contract on the pricing of independent offers.

Although the argument is general, Lerner and Tirole (2004) focus on *patent pools*, where innovators collaborate to license bundles of more or less related patents. Patents tend to be complements at low prices and substitutes at high prices. When prices are low, users strictly prefer to use all patents conditionally on adopting the relevant technology, so a decrease in the price of one patent raises the demand for the other patents. But with high prices, users may want to use a subset of patents and thus the patents compete with each other. The policy advice is thus to allow the formation of patent pools, but to insist that the pool admits independent licensing.

A specific problem related to the pricing of patents is that relatively minor innovations can command a very high price if they happen to become part of a technology standard. Indeed, an innovation that is worthless if the agreed standard includes a substitute innovation may be extremely valuable if it is instead included in the standard. Lerner and Tirole (2014) argue that an unregulated marketplace will entail too high prices for such standard-essential patents, and that vague regulations imposing "fair pricing" will merely entail extensive litigation (as is commonly observed). They propose that patent-holders should commit to prices before standards are decided, as this will align private incentives with social objectives.

Network competition and two-sided markets Current industrial policy has to deal with new forms of competition, often linked to the introduction of new technology. Two examples are *network competition* (Laffont, Rey and Tirole, 1998a, 1998b) and *two-sided* (*platform*) *markets* (Rochet and Tirole, 2003, 2006). Tirole is a leader in the study of these new forms of competition. Network competition will be discussed in Section 5.1. In a two-sided market, the two sides (say, buyers and sellers) interact via a platform. Examples include operating systems, payment cards (credit, debit or charge cards), shopping malls, and TV-channels.

A concrete example of a two-sided market is given by credit-card networks (such as Visa, Mastercard, or American Express). The two sides of the market are the consumers and the retailers. If a certain credit-card company charges retailers a high transactions fee, a retailer might decide to not accept this card. This might, however, lead consumers who prefer this card to shop elsewhere. On the other hand, there is a positive feedback loop between merchant acceptance and consumer usage.[37] In a pioneering article, Rochet and Tirole (2003) analyzed the equilibrium of this kind of two-sided market, and studied

[37] Rysman (2007) found empirical evidence for such a positive feedback loop in the regional correlation between consumer usage and merchant acceptance.

its welfare properties.[38] The model was generalized in Rochet and Tirole (2006). Key questions addressed in these articles include the equilibrium pricing structure, and the extent to which consumers and retailers use more than one network ("multi-homing").

In platform markets, demands from the two sides can be very different. For example, advertisers might desire that there be many viewers or readers, whereas viewers and readers often prefer that there be few advertisers. As a result, prices that would be clearly anti-competitive in a one-sided market can be highly competitive in a two-sided market. For example, offering newspapers for free would be a sign of predatory pricing if the newspaper's only source of revenue came from readers, but may be entirely consistent with competitive pricing if advertising revenues are important. Because conventional tests for anti-competitive behavior are not applicable in platform markets, the work by Rochet and Tirole (2003) has had an immediate impact on competition policy (see Evans, 2009). This work has also influenced the ongoing debate about network neutrality – i.e., regulation prohibiting broadband-access providers from charging content providers for access to broadband customers (see Musacchio, Schwartz and Walrand, 2009).

4 Competition Policy

Since the days of Adam Smith, economists have realized that firms with market power may try to restrict competition in their industries, whether by collusive agreements, predatory behavior, or other means. Competition policy aims to prevent such activities. They are subject to legislation in many nation states, as well as in international agreements such as the European Union.

Regulated firms typically interact with other firms in various ways, so oligopoly theory, optimal regulation and competition policy are closely linked topics. In industries such as railways, telecommunications and electricity, the network infrastructure itself may constitute a natural monopoly, but downstream competition may be possible if competitors can access the network. This was mentioned in Section 2.3 and will be further discussed in Section 5.1.

When discussing competition policy it is useful to distinguish horizontal practices (involving firms in the same industry) from vertical practices (involving upstream and downstream firms).

Horizontal practices Horizontal agreements may involve joint licensing or (more generally) co-marketing agreements and, as we saw in Section 3, Tirole has devised robust competition policies in that area. Alternatively, rather than limiting competition by soft cooperation, firms may use aggressive tactics to shut out their rivals, for example by pricing below cost. Of course, outlawing low prices is problematic for many reasons. One reason is that firms may benefit from setting prices below cost in some segments even under sustained fierce competition; recall the discussion of two-sided markets in Section 3.4.

Horizontal mergers constitute an extreme form of limits to competition. The game-theory revolution, which Tirole helped launch, has shaped the modern understanding

[38] Caillaud and Jullien (2003) and Armstrong (2006) were other important early contributions to this topic.

of horizontal mergers, and this new understanding has influenced competition policy in the U.S. and the EU (see Whinston, 2007).[39] As always, game theory suggests a rather nuanced view: the effects of a merger depend on a host of factors, such as markets shares, demand elasticities, price-cost margins, and the ability to price discriminate. To obtain definite results, Berry and Pakes (1993) advocate merger simulations, using a framework for dynamic oligopoly analysis inspired by the work of Maskin and Tirole. Here, Tirole's policy influence is thus indirect rather than direct.

Vertical practices: background Jean Tirole has analyzed vertical practices in detail and in this area his work has had a great influence on both the academic literature and on competition policy. We devote the rest of this section to this topic.

Most firms do not sell their products directly to consumers but rather to other firms, who either use them as inputs in production, or sell them to consumers. Vertical relationships are often characterized by contractual agreements known as vertical restraints. For example, an exclusivity agreement between a manufacturer (the upstream firm) and a retailer (the downstream firm) may specify that no other retailer can carry the manufacturer's product within a given territory, a region or an entire country. Alternatively, an upstream firm may merge with a downstream firm in a vertical merger, and then deny its downstream rivals access to an input it produces so as to gain market power, so-called vertical foreclosure.[40]

The Chicago School (Posner, 1976, 1981; Bork, 1978) argued that foreclosure is always an irrational strategy. It cannot increase market power, it was argued, because upstream firms can fully exploit their market power without engaging in exclusion. Therefore, the motivation behind vertical restraints and integration must be to enhance efficiency rather than to restrict competition. For example, the service a retailer provides to its customers typically yields a positive externality on a supplying manufacturer, since it influences the demand for the product. If the retailer disregards this externality, the service levels may be inefficient. If an exclusivity agreement encourages the retailer to provide better service, then it enhances efficiency.

The Chicago School's arguments seemed convincing to many, and in the early 1980s the principle of vertical foreclosure was indeed removed from the Merger Guidelines of the U.S. Department of Justice. However, as we will see, vertical contracting arrangements have ambiguous welfare implications. This new and more nuanced view, which has influenced academics, government enforcement agencies, and courts, is to a large extent due to Jean Tirole and his coauthors. Kwoka and White (2013) discuss the impact of the modern analysis in a number of recent court cases.

[39] As discussed above, the Chicago School challenged the usefulness of the structural presumption, i.e., the negative relationship between market concentration and performance. Since then, economists have become less inclined to simply rely on concentration measures when evaluating the social cost of horizontal mergers.

[40] The literature on vertical restraints also pays attention to the case in which a monopolist sells directly to customers, but engages in "horizontal foreclosure" by bundling the monopoly product with a potentially competitive product. (For example, Windows was once bundled with Internet Explorer.) The seminal modern analysis of horizontal foreclosure is due to Whinston (1990).

Vertical practices: the Coase theorem In the modern literature, vertical contracting is seen as a single-principal multi-agent problem, where the principal – typically an upstream firm – designs a contract for his agents – typically a number of downstream firms. In this setting, while vertical restraints may help internalize externalities between the contracting upstream and downstream firms, it may also entail negative externalities on third parties (final consumers, or other firms). Government regulation could therefore be justified, but the heterogeneity of markets makes it hard to draw general conclusions. Similarly, the effects of vertical integration are now seen to vary across firms and markets. Detailed analyses of specific markets are required to reliably identify practices that harm competition and should be prohibited.

Before proceeding to some formal examples, we recall the Coase theorem: if contracting between two parties is perfectly frictionless, then they can always negotiate an optimal outcome and institutions are not so important. For this reason, recent generations of economists came to question old and rather simplistic arguments concerning the costs and benefits of vertical integration. For example, it had previously been claimed that vertical integration would avoid double marginalization (Spengler, 1950). That is, trade within the firm will take place at marginal cost, whereas trade between firms will not. But the Coase theorem implies that the double marginalization argument must rely on some restriction on contracting between the two firms. Indeed, upon closer scrutiny, the argument restricts inter-firm trade to linear price schedules. A non-linear (two-part) tariff would permit a separation between the division of surplus (which can be implemented through a lump-sum component) and the price of trading an extra unit (which could be set equal to marginal cost), and this would eliminate double marginalization. Much inter-firm trade is in fact conducted under this kind of non-linear pricing, so ruling it out by assumption seems quite arbitrary. The challenge is to compare different institutional arrangements without making *ad hoc* restrictions on contracting, i.e., by focusing only on fundamental frictions. Such more fundamental models are not only more reliable for policy analysis, but they often entail new testable predictions.

In the following, we consider two important early contributions which followed this path. In Rey and Tirole (1986), the friction is asymmetric information about the state of the world. Hart and Tirole (1990) the friction is instead the commitment problem caused by the possibility of secret contracting. These analyses provided two quite different reasons for why exclusionary practices, although privately rational, may have negative welfare effects.

Vertical practices: asymmetric information First, consider Rey and Tirole's (1986) model. The upstream firm is a monopolistic manufacturing firm. The downstream industry consists of retailers who are (potentially) competitive. The demand curve facing the retailers is $q = d - p$, where q is quantity sold to the final consumers, p is the consumer price chosen by the retailers, and d a stochastic demand parameter. To maximize profit, the manufacturer would like p to vary with d. However, there is asymmetric information: while retailers observe the true value of d, the manufacturer does not. The manufacturer must therefore sell the product to the retailers at a per-unit price p_w which does not depend on d. If the retailers are allowed to compete freely with each other, they will all set $p = p_w$ and make zero profit (assuming there is no cost of retailing, which wouldn't change the argument). With competition p is therefore independent of d.

Now suppose the manufacturer eliminates the competition among retailers through an exclusivity clause: each retailer can obtain an exclusive regional dealership in exchange for a franchise fee A (in addition to a per-unit price p_w). Other retailers are barred from selling in this region, i.e., there is foreclosure. This arrangement is beneficial to the manufacturer because the local monopolist will make p a function of d. The drawback is that the retailer will be exposed to risk: he has to pay A even if there is a negative demand shock. (A cannot depend on d since the manufacturer cannot observe d.) If the retailer is risk-averse, then the manufacturer will insure him by reducing A and raising p_w (thus indirectly also raising p). Still, as long as the retailer's degree of risk-aversion is not too great, the benefit to the manufacturer from the exclusivity clause exceeds the cost, so he will use it. But one can show that the exclusivity agreement raises the expected consumer price p which harms consumers. Indeed, if the retailers are sufficiently risk-averse, the total (consumer plus producer) surplus is reduced by the exclusivity clause. Therefore, an anti-competitive vertical restraint, although privately optimal for the upstream firm, may be socially harmful.

Vertical practices: limited commitment Hart and Tirole (1990) considered a different kind of friction to contracting: the inability to make binding commitments. Except for this constraint, they did not restrict the firms to any particular contractual arrangement, but rather derived the optimal contracts from fundamental assumptions. In their model, there is again a monopolistic upstream manufacturer, and a potentially competitive downstream industry, which as before consists of retailers facing a demand curve $q = d - p$. However, now there is symmetric information about d.

As mentioned, the Chicago School had argued that a rational upstream firm would not use foreclosure to extend its market power. By contrast, Hart and Tirole show that in general the upstream monopolist cannot fully exploit his monopoly power without resorting to exclusion, and therefore foreclosure may be a rational strategy.[41] To see this, consider the following two-stage game. In stage 1, the manufacturer offers retailer i a contract in the form of a non-linear pricing schedule $T_i(\cdot)$; the retailer then orders q_i units and pays $T_i(q_i)$ to the manufacturer. In stage 2, retailer i sells his q_i units to consumers at price $p = d - q$, where $q = \sum_{i=1}^{n} q_i$ is the total number of units ordered by all n retailers in stage one.

Suppose all contracts offered in stage 1 are publicly observed. The manufacturer can then extract the full monopoly profit without any exclusion, as argued by the Chicago School. He simply offers $q_i = Q^m/n$ units to each retailer, at the per-unit price $p^m = d - Q^m$, where Q^m denotes the monopoly output. The retailers all accept this offer as they make zero profit. Because total output nQ^m/n equals the monopoly output Q^m, the manufacturer earns the monopoly profit. There is no need to exclude any retailer.

But now suppose contracts can be offered secretly, so the contract offered to retailer i is not necessarily observed by the other retailers. It can be easily checked that if $n-1$ retailers each order Q^m/n units, as in the previous paragraph, then the manufacturer and retailer i can increase their joint profit by increasing q_i above Q^m/n. In fact, the optimal quantity would be given by the standard Cournot reaction function, given that the other

[41] Other notable work on foreclosure includes Salinger (1988) and Ordover et. al. (1990).

$n-1$ retailers sell the aggregate quantity $(n-1)Q^m/n$. Thus, if contracting can take place in secret, and if the manufacturer can use this secrecy to make mutually beneficial deals with a retailer, then selling Q^m/n units to each retailer is not credible.[42]

In the Hart-Tirole model, the manufacturer has a commitment problem: with a competitive retail market, he would like to promise to only deliver Q^m/n units to each retailer. But if contracts are secret, or can be secretly renegotiated, such a promise is not credible. The manufacturer has an incentive to approach any retailer and offer him more. The unique equilibrium output is then the Cournot output, so the manufacturer does not earn the monopoly profit. However, if he can commit to dealing exclusively with only one retailer his monopoly power is restored. If this is not possible, a vertical merger between the manufacturer and a retailer solves the problem: it will be an equilibrium for the manufacturer to sell Q^m to his downstream affiliate, exclude all other retailers, and earn the monopoly profit. In short, exclusion is a rational strategy. Of course, consumers are harmed by the exclusion, since prices will increase to p^m.

In the Hart-Tirole world, upstream firms would like to commit themselves to not behaving opportunistically towards downstream firms, but if they are unable to do so then the equilibrium outcome may be quite competitive. Indeed, as $n \to \infty$ an upstream monopolist cannot extract any rents at all. Vertical integration restores the monopolist's market power and thereby reduces the total social surplus.[43] Other effective commitment devices might include renting (instead of selling) and contract clauses such as most-favored-customer clauses or retail-price maintenance. Ironically, antitrust authorities' challenge of price discrimination – insisting that all business customers should receive the same price – helps the monopolist to extract rents.

Another irony is that the basic message had already been broadly understood in other contexts. As Rey and Tirole (2007) note, the economics profession had long ago realized that patent holders and franchisors need to limit downstream competition in order to extract rents. For example, if someone makes a process innovation, and the potential buyers are engaged in tough price competition with each other, the equilibrium price of the patent is much higher if one buyer gets the exclusive right to utilize the new technology than if it is sold to all the competitors. Also, Coase (1972) had pointed out that a durable-goods monopolist needs a credible commitment device for customers to buy immediately instead of waiting for the price to drop – the famous Coase Conjecture says that in the absence of credible commitments the monopolist is unable to extract any rent. It was only the game-theoretic formalization and proof of this conjecture, by Gul, Sonnenschein and Wilson (1986), that gave a deep enough understanding of the monopolist's problem to enable the powerful policy analysis initiated by Hart and Tirole (1990).

We have thus seen that vertical restraints have ambiguous welfare effects. To reliably

[42] There are some technical issues regarding how to specify the retailer's (out-of-equilibrium) beliefs when he gets a surprising offer to make a secret deal. But intuitively, the Hart-Tirole argument is convincing because it only relies on the manufacturer and retailer being able to make mututally beneficial trades, given the equilibrium contract offers made to the other retailers (which, technically, is assured by assuming passive beliefs).

[43] This assumes the merger does not produce other efficiency gains that more than compensate for the increased market power. As 2009 Laureate Oliver Williamson (1968) emphasized, the social cost of a merger should always be balanced against possible efficiency gains within the merged firm.

identify socially harmful practices, one must perform a detailed analysis on a case-by-case basis. As an example, Chipty (2001) found that vertically integrated cable-TV operators in the U.S. tend to exclude rival program services, creating market power that reduces consumer welfare – but he found that this anti-competitive effect is outweighed by the efficiency gains of integration.

5 Applications

In this section, we discuss regulation in two industries that Tirole and his coauthors have analyzed in depth, namely telecommunications and banking.

5.1 Regulation of Telecommunications

Because of the significant fixed costs involved in building a telecommunications network, the industry has historically been considered a natural monopoly.[44] The industry was dominated by an incumbent, either a private regulated firm like AT&T in the United States, or a public enterprise like British Telecom (BT) in the UK. A reform movement in the 1980s led to major changes: a wave of privatizations, and a switch from rate-of-return towards price-cap regulation.[45] It became commonly accepted that new entrants should be allowed to compete with the incumbents within most telecommunications segments. Among the motivations for these reforms was a belief that incumbent monopolists had insufficient incentives to reduce costs and improve quality, and that prices were determined by fairly arbitrary accounting procedures rather than by economic efficiency.[46] In their 2000 book, *Competition in Telecommunications*, Laffont and Tirole analyzed the regulatory reforms and the emergence of competition in the telecommunications industry, using a sequence of models inspired by their previous work on regulation.

Price caps and Ramsey pricing As mentioned in Section 2.3, Laffont and Tirole (1990a) showed that, under plausible assumptions, the efficient price structure for a multi-product monopolist is provided by Ramsey pricing formulas. Accordingly, Laffont and Tirole (2000, Chapter 2) argue that Ramsey pricing is a reasonable benchmark for efficiency. They further show that price-cap regulation can implement Ramsey pricing and thus lead to allocative efficiency. Intuitively, Ramsey prices are "business oriented" in the sense that markups are proportional to the inverse demand elasticity, a rule an

[44] For example, wiring every home twice in order to create two competing local networks would be very expensive.

[45] For example, AT&T was broken up in 1982 and BT was privatized in 1984. In 1989, the FCC introduced price-cap regulation for AT&T, replacing the traditional rate-of-return regulation. Sappington and Weisman (2010) document and evaluate the spread of price-cap regulation in the telecommunications industry.

[46] Although we focus on telecommunications, other industries such as electricity, gas, postal services and railroads have faced similar issues. However, as Laffont and Tirole (2000) emphasize, all these industries differ in many important ways. In the spirit of Tirole's other contributions, one cannot simply translate an analysis of one specific industry to other industries without careful consideration of these differences.

unregulated monopolist would also follow. The problem is that the unregulated monopolist would set the average price too high, even though the relative price structure would be appropriate. Laffont and Tirole show that this can be corrected by a price-cap which constrains the firm's average price at the right level; subject to this constraint, the firm can adjust relative prices. The decentralized price structure will become business oriented and hence Ramsey oriented.[47]

Laffont and Tirole (2000, Chapter 2) also discussed prospective drawbacks of high-powered incentive schemes such as price-caps. These schemes leave large rents to efficient firms, and this is socially costly. Moreover, large rents give rise to a credibility problem: when a regulated firm makes large profits, there will be political pressure to revise the regulatory policy and expropriate the profits.[48] Laffont and Tirole emphasized that those who believe in high-powered incentive schemes must be prepared to oppose such revisions, for otherwise the *ratchet effect* may eliminate the incentives for cost-minimization. As mentioned in Section 2, other potential problems with high-powered incentive schemes include degraded service quality and regulatory capture. Therefore, in order to function as intended, stronger incentives typically need to be accompanied by better monitoring and other organizational reforms.

Access pricing In network industries, incumbents often control bottlenecks to which competitors in the retail market must be given access. For example, a new long-distance telephone company such as Mercury in the UK may need access to the local telephone network controlled by BT, the incumbent.[49] In fact, Mercury *bypassed* the local network by building direct links to large businesses, although it relied on access to BT's local network to provide long-distance services to residential customers (Laffont and Tirole, 2000, Chapter 1).[50]

What price should an entrant such as Mercury be charged for access? The dominant paradigm had been marginal-cost access pricing. However, Laffont and Tirole argued that access pricing is just a special case of regulation of a multi-product firm. Since the fixed cost of building and maintaining the network must be paid for, the principles of Ramsey pricing apply. It is perfectly appropriate to set the access price above marginal cost to help finance the fixed cost.

Laffont and Tirole (2000, Chapter 3) derived formulas for *efficient access pricing.* The key to their analysis is to consider the incumbent as subcontracting long-distance services to the new entrant. One can then view the incumbent as producing two long-distance services, one internal to the firm and one outsourced. For both services, efficient Ramsey-pricing implies markups which depend on marginal cost and demand elasticities. In particular, the formulas take into account cross-elasticities – the price of a service should be higher if a higher price raises the demand for another service. Correctly computed Ramsey prices therefore take into account possible "cream-skimming", whereby

[47] To calculate the price average, each price p_j should be weighted by the forecasted output level of good j. Thus, to implement the optimal price cap may be computationally and informationally challenging.

[48] Conversely, if the regulated firm makes losses, it will lobby for changes in the regulatory policy.

[49] Many other industries have similar bottlenecks: railroad tracks and stations, power transmission grids for electricity, pipelines for natural gas, etc.

[50] Laffont and Tirole (1990c) develop a formal model of optimal regulation when high-demand customers may bypass the incumbent's network and establish a direct link to one of its rivals.

an entrant attempts to attract the incumbent's most lucrative customers. Intuitively, if an entrant simply steals customers away from the incumbent without creating additional value, this should be reflected in access prices. Giving the incumbent the responsibility for covering the fixed cost of the network all by itself, and letting entrants free ride by paying very low marginal-cost access prices, would inefficiently distort consumer choices towards the entrant.[51] Moreover, if the long-distance segment becomes very competitive, the incumbent will primarily have to recover the fixed cost by setting high prices in other segments where it still has a monopoly, such as local telephone services, implying large distortions on those segments.

Although the formulas may be complex, the economic logic behind efficient access pricing is straightforward: the incumbent can be viewed as supplying multiple services, and optimal pricing follows familiar Ramsey principles. Laffont and Tirole (2000) not only presented the academic arguments, but also crafted extensive verbal explanations aimed at practitioners and policy-makers with little training in economic theory. Moreover, they showed how the same principles apply in other situations, such as peak-load pricing, price discrimination and the adoption of new technologies. Finally, efficient access (Ramsey) prices are once again business oriented so they can be decentralized to the firm. The regulator only needs to fix the average price level (although calculating the right level can be a complex task).

Competitive pricing Once entrants have access to the network, how should prices in the competitive segment (e.g., long-distance phone calls) be determined? The dominant paradigm has been that regulating the competitive segment is unnecessary, since competition will foster low prices for retail customers. However, Laffont and Tirole (2000) showed that a strict access-pricing policy (such as marginal cost pricing), that prevents the incumbent from making money from access, may yield incentives to deny access by other methods than pricing. For example, the incumbent may claim that access requires a costly upgrade to the network. Verifying such claims can be difficult and involve heavy-handed regulation. If the incumbent manages to deny access, then the rival is excluded from the competitive segment and the incumbent can extend its market power from the regulated segment, where its pricing is constrained, into the competitive segment, where its pricing is unconstrained. This problem could be alleviated by either setting access prices above marginal cost, as suggested by Ramsey formulas, or regulating the incumbent's pricing in the competitive segment. In either case, the solution runs counter to the doctrine of deregulating competitive segments while enforcing tight caps on access pricing.

More generally, Laffont and Tirole (2000) argued that asymmetric schemes – where some parts of the incumbent's business are tightly regulated and others less so (or not at all) – give rise to perverse incentives. For example, the regulated firm can benefit from cross-subsidization, using both accounting and "real" decisions. It may allocate its most productive inputs (such as the most skilled managers) to the unregulated segment, and its least productive inputs to the regulated segment. Even if the regulated segment has a price-cap, the ratchet-principle implies that, in reality, the cap will be adjusted to track

[51] On the other hand, very high access prices can lead to inefficient bypass, whereby the entrant establishes direct links to the most lucrative customers (see Laffont and Tirole, 1990c).

realized costs. Thus, allocating less productive managers to the regulated segment will eventually allow the incumbent to raise prices there, while its most skilled managers will generate immediate profits in the unregulated segments.

Laffont and Tirole (1994, 1996, 2000, Chapter 4) proposed a global price cap, where all product lines are treated symmetrically. Only the average price is constrained which, as mentioned above, will induce the firm to set appropriate Ramsey prices. In particular, network access should be treated as any other good, and be included in the computation of the global price cap. This makes access services a normal business segment, and mitigates the incumbent's incentive to exclude competitors. Laffont and Tirole emphasized that the incumbent may still attempt to hurt its rivals by predatory pricing, and proposed the Baumol-Willig "efficient-component pricing rule" as a possible test for predation.[52]

Two-way access Nowadays, more and more entrants – mobile operators, cable companies, Internet-service providers – establish their own networks. This raises the issue of *two-way access*: different networks must be interconnected and services involving multiple networks must be priced. For instance, if A makes a phone call to B, A's network must pay a so-called termination charge to B's network – how will these charges be determined?

International calls represent a classical case of the two-way access problem. Traditionally, when a customer in country A called a customer in country B, the national telephone company in country B would charge a termination fee from the national company in country A. Although those fees were negotiated between large national companies, termination fees would often be quite high. Indeed, the fees would often seem to exceed the level that would maximize the companies' joint profits. Laffont, Rey and Tirole (1998a, 1998b) developed a formal model of two-way access, based on the assumptions that the receiver does not pay for calls (the caller's company pay termination fees) and that telephone companies are free to set retail prices. The model was further elaborated in Laffont and Tirole (2000, Chapter 5).[53] Within this framework, they proved that termination fees are inefficiently high under a variety of existing and proposed regulations. A regime that encourages head-to-head competition is problematic, since each firm has a motive to charge high fees on its monopoly segment, i.e., the termination fee. But a regime that allows firms to cooperate may be no better, since the firms have a joint incentive to soften retail market competition by setting high termination fees. Cooperative agreements on mutual access charges may in effect facilitate collusion in the retail market.[54] Motivated by such problems, Laffont, Rey and Tirole discussed new pricing models, some of which have later been put to use as the number of mobile-telephone networks has proliferated.

5.2 Regulation of Banks and Financial Markets

Jean Tirole has made several important contributions to the area of financial regulation. The first question is why financial intermediaries, such as banks and insurance companies, need to be regulated at all.

[52] For further discussion of entry-deterrence when access prices but not retail prices are regulated, see Armstrong and Sappington (2007, Section 5.1.4).

[53] A similar model was independently developed by Armstrong (1998).

[54] However, Laffont and Tirole (2000, Chapter 5) discuss a number of factors, specific to the telecommunications market, that make it difficult for firms to collude.

The basic reasons for regulation A first reason for regulation is that financial institutions are highly interconnected, through complex, often short-term, borrowing and lending arrangements. When a single large financial institution goes bankrupt, insolvency may therefore quickly spread to other financial institutions in a systemic financial crisis with immense negative consequences for the economy, such as the one that followed the Lehman failure in 2008. A second reason is that many *de facto* lenders to financial institutions are ordinary consumers and households, e.g., through deposits and pension savings. Since households may not have sufficient information to evaluate and monitor the health of the banks where they keep their deposits, consumers can suffer severe consequences when a financial institution fails. This lack of information can also trigger financial panics where many individuals "run" to withdraw their deposits from a bank that is rumored to be failing (even if the rumor happens to be false), effectively then causing the bank to fail.

For these reasons, the government needs to be able to rescue – "bail out" – failing institutions to avoid systemic crises and bank runs, and to protect consumers. But when failing financial institutions are bailed out *ex post*, this may lead to moral hazard *ex ante*, as bank managers have incentives to take on higher financial risk than otherwise. A regulator may therefore need to restrict leverage and risk-taking at financial institutions *ex ante*, such as through minimum requirements on bank equity capital and liquidity. A common theme in Tirole's work is the design of financial regulation that optimally trades off *ex post* efficiency, i.e., intervening to avoid systemic crises, with *ex ante* efficiency, i.e., mitigating the moral-hazard problems that produce the prospect of crises to begin with.

Interbank markets Rochet and Tirole (1996a) built on the work of Holmström and Tirole (1998, discussed in Section 6.2) to model the interconnectedness of banks and the case for regulation. While decentralized interbank markets are prone to systemic crises, decentralized interbank markets encourage peer monitoring across banks. This benefit is undermined when governments are expected to bail out failing banks *ex post*, since an anticipated bail-out makes it less worthwhile for a bank to monitor its counterparties *ex ante*. The paper analyzes various regulatory mechanisms to deal with this problem, and foresees many of the problems that would eventually hit the financial system in the 2008 crisis. Similarly, Rochet and Tirole (1996b) compared the properties of different clearing and settlement systems, which have been at the forefront of financial regulation in the aftermath of the financial crisis.

Consumer interests In their 1994 book, *The Prudential Regulation of Banks*, Mathias Dewatripont and Tirole focused on another problem: many bank lenders, such as depositors, are too small and dispersed to exercise any control over the bank. Then, the role of regulation is to represent the interests of these lenders, exercising control over banks and mitigating excessive risk-taking by bank managers. Dewatripont and Tirole used a financial-contracting framework to analyze optimal regulation regarding solvency rules, recapitalizations, accounting, and securitization.

Collective risk taking Emmanuel Farhi and Tirole (2012a) showed that financial institutions may, collectively, use too much short-term debt and engage in correlated investment strategies. The reason is that this makes it more likely that a certain bank will be bailed out in case of failure, because other banks will have problems at the same time. Put differently, the choices of leverage and risk taking by different financial institutions are strategic complements, exacerbating the risk of systemic crises. Based on this insight, Farhi and Tirole derived optimal regulatory policies, contrasting interest-rate policies (i.e., lower interest rates in a crisis to facilitate refinancing) and transfer policies (i.e., direct transfers to financial institutions in a crisis). Optimal policies involve *ex ante* liquidity requirements as well as interest-rate policies, despite the latter having distortionary costs. They also provided a rationale for so-called macro-prudential regulation, where optimal regulatory interventions are based on the status not only of individual financial institutions but also of the financial system as a whole.

Exit from financial crises Tirole (2012) asked how one may "jump-start" a financial market in a crisis. Crises are typically triggered by adverse news about the value of financial assets, like the negative shock to the perceived value of U.S. mortgage-backed securities in the 2008-09 crisis. Due to adverse selection, small adverse news can completely freeze up the market for financial assets. As a bank has better information about its own assets, when it tries to sell assets to finance necessary investments, this may lead other market participants to believe that it has inside information about its assets being of low quality. When the market price of bank assets falls, banks with high-quality assets find selling their assets to finance investments less worthwhile. As a result, the asset market dries up, banks are not able to finance their investments, and the financial system cannot restore its solvency. To counter such developments, many regulators (including the Federal Reserve and the ECB) have intervened in asset markets, offering to buy bank assets. This is costly to tax payers, however, since banks with low-quality assets have the largest incentive to take advantage of this offer. Tirole derived the optimal policy for dealing with the problem: to buy back the weakest assets, and then provide financing to banks with assets of intermediate quality, while retaining these assets on the firms' balance sheet. This leaves only the highest quality assets for trade, which restores the functioning of markets.

6 Other Contributions

Jean Tirole has made seminal contributions to many fields outside of regulation and IO. In this section, we mention some of these, with the caveat that our treatment must necessarily be a rudimentary one.

6.1 The Toolbox: Game Theory and Mechanism Design

Among Tirole's research on game-theoretic solution concepts, his aforementioned work on Markov Perfect Equilibrium stands out (Maskin and Tirole, 2001). But his work on Perfect Bayesian Equilibrium (PBE) has also been highly influential (Fudenberg and Tirole, 1991a). The notion of PBE relaxes the strong consistency requirements inherent in the definition of sequential equilibrium (Kreps and Wilson, 1982). PBE is intuitively very appealing and frequently used in applied work. Fudenberg and Tirole (1983) studied a two-person extensive-form bargaining game with incomplete information. In such games, a player's actions may convey information about his type, and it is not obvious how the opponent will react to a "surprising" (out-of-equilibrium) action. By applying the concept of PBE, the authors were able to study how exogenous parameters such as bargaining costs influence the probability of concessions and bargaining breakdowns. Fudenberg and Tirole (1991b) remains the most comprehensive graduate textbook in game theory.

Tirole has also conducted research on mechanism design. Here, his work on games in which the designer (principal) has private information stands out (Maskin and Tirole, 1990, 1992). For example, a regulator may have private information about the demand for a regulated good. When the principal proposes a contract to the agent, the proposal may signal the principal's private information. The critical issue is thus to understand how the agent's beliefs are affected by the proposal. Maskin and Tirole (1990) considered the case of private values, i.e., where the principal's private information does not directly enter the agent's payoff function. They established a correspondence between the (one or many) PBE of the game, and the competitive (Walrasian) equilibria of a fictitious exchange economy where the traders are the principal's different types. Maskin and Tirole (1992) established a set of results in the more difficult case of common values.

Tirole has made several other influential contributions to principal-agent theory, covering topics such as income-smoothing (Fudenberg and Tirole, 1995) and contract renegotiation (Fudenberg and Tirole, 1990).

6.2 Financial Intermediation and Liquidity

Together with Bengt Holmström, Jean Tirole has made a number of influential contributions that explore the effect of liquidity on financial markets and intermediation.

Holmström and Tirole (1997) built a simple model to analyze the role of financial intermediary capital. Here, firms are liquidity constrained because of moral-hazard problems, and financial intermediaries can partly alleviate these moral-hazard problems by monitoring. However, intermediaries may also act opportunistically themselves, and so their ability to raise external funds are limited by their internal equity. The authors derived predictions for how investment and costs of capital will react to contractions in firm capital (collateral squeeze), in intermediary capital (credit crunch), or in uninformed capital (savings squeeze). They also prescribed that optimal capital requirements for intermediaries should be pro-cyclical, since it is easier to ensure monitoring by intermediaries in recessions, when returns to monitoring are higher. Pro-cyclical capital requirements have become part of the new financial regulation in the wake of the financial crisis of 2008-2009. The Holmström-Tirole (1997) model has indeed become a workhorse for analyzing issues in financial intermediation as well as corporate finance.[55]

Holmström and Tirole (1998) highlighted the importance of liquid assets to the financial system, and the government's role in providing such assets. Firms need to ensure access to future liquidity to meet future shocks, and can do so by hoarding liquid assets *ex ante*. But this is inefficient, since firms will keep excess liquidity when it is not needed. A more efficient way for the firms to insure against future shocks is to get a credit line from a bank, which it can use if shocks are realized. However, there must be enough

[55] See Acharya et al (2007), Allen et al (2011), Parlour and Plantain (2008), and Chen (2001).

liquidity in the banking system as a whole to honor the claims of firms when they need it. This is difficult in the wake of macroeconomic shocks when many firms experience shortfalls at the same time. Holmström and Tirole used this argument to highlight a role for public liquidity provision. Governments issue public bonds, which serve as a store of value for the private sector and can be liquidated in case of a liquidity shortfall.[56]

6.3 Bubbles in Asset Markets

A long-standing question in asset-pricing theory is whether we can have rational bubbles – i.e., a price above the net present value of the asset's returns, broadly defined. For example, the high price of a scarce stamp is probably best seen as a bubble: people pay dearly for such stamps, not because they yield a stream of returns (in money or viewing pleasure), but because they expect the stamp to increase in value. A rational bubble is sustained by the expectation that, on average, its value will increase at the discount rate. Such a rational bubble may not inevitably burst, but can instead grow indefinitely.

Tirole has made two fundamental contributions to the theory of rational bubbles. In Tirole (1982), he proved that purely speculative bubbles cannot exist if markets are complete and people are sufficiently rational. In Tirole (1985), he showed that if markets are incomplete then rational bubbles can not only exist, but also perform a useful function. While this possibility had already been raised by 1970 Laureate Paul Samuelson (1958), his result assumed that there were no other stores of value. Building on previous work by 2010 Laureate Peter Diamond (1965), Tirole showed that this essential insight carries over to a growing economy where people can save in physical capital. As economists continue to investigate whether real-world financial markets are incomplete enough to foster rational bubbles – and how this ought to shape monetary and fiscal policies – they owe an intellectual debt to Samuelson, Diamond, and Tirole for providing the right foundations.

More recently, Tirole has combined his early work on bubbles with his more recent work on financial regulation in joint research with Emmanuel Farhi.[57]

6.4 Organizational Economics

Jean Tirole has made seminal contributions to organizational economics. Tirole's (1986a) principal-supervisor-agent model, mentioned in Section 2.5, is the workhorse for modeling hierarchies in organizations. Its three-tier structure describes the essence of many situations better than the standard principal-agent model (a two-tier structure without a supervisor). Many organizations have at least one layer of supervisors, who report

[56] Holmström and Tirole (2001) built on Holmström and Tirole (1998) to derive asset pricing implications from the private sector's liquidity demand. They showed that assets with high (low) value in states of aggregate liquidity needs will trade at higher (lower) prices and equivalently have lower (higher) expected returns.

[57] Farhi and Tirole (2012b) analyzed bubbles in the context of Holmström and Tirole's (2008) liquidity-shortage problem. Bubbles are more likely to emerge, the scarcer the supply of outside liquidity and the less pledgeable corporate incomes. A positive aspect of bubbles is that they alleviate financial constraints of firms, and boost investment by increasing corporate access to sources of value. A negative aspect of bubbles is that they are a very imperfect form of liquidity, since they tend to burst exactly when the corporate sector needs liquidity the most.

information to principals on the behavior or circumstances of agents. For example, accountants primarily collect and communicate such information. A general theme of the literature generated by Tirole's article is that low-powered incentives may be an optimal response to the threat of supervisor-agent collusion. Instead of being tough watchdogs who reveal when the agent's task is easy, supervisors tend to act as advocates for inefficient agents, revealing only information that suggests the task is difficult. As a result, agents who claim to be high-cost, but cannot be verified as such, are given extremely low-powered incentives.

Another influential paper in organizational economics is Aghion and Tirole (1997), which used the model of incomplete contracting due to Grossman and Hart (1986) to analyze the allocation of decision authority in organizations.[58] Delegating tasks increases the initiative of agents, but at the cost of the principal losing control. One implication is that delegation increases the agents' incentives to collect and use information as a basis for decisions. Empirical work has examined this prediction, and found considerable support, for example by examining the reliance on soft versus hard information in bank-lending decisions (e.g., Berger et al, 2005; Liberti and Mian, 2009).

Yet another significant contribution is that of Dewatripont and Tirole (1999), which considers the phenomenon of advocates in organizations, i.e., agents whose goal is to defend a specific "cause" rather than the overall welfare of the organization. One example is courts, where lawyers explicitly defend the interests of the defendant, while prosecutors do just the opposite. The rationale for the advocates organization is that competition among advocacy groups may lead to more efficient decisions, due to more efficient collection and use of information.

6.5 Corporate Finance

Tirole has also made contributions to corporate finance. One is his graduate textbook (Tirole, 2006). Like his textbook on IO, it provides more than a recap of earlier work, by synthesizing a vast literature within a unified framework, as well as containing a number of new applications and results. Not surprisingly, it has become a standard reference and is used in graduate corporate-finance courses at universities around the world.

Another important piece is that of Holmström and Tirole (1993). They considered how to provide incentive-compensation contracts to ensure that a manager provides sufficient effort. They first showed that the stock price of a firm can only be a sufficient statistic in the manager's compensation contract when speculators have an incentive to collect and profit from information. This requires a sufficient amount of liquidity in the market, which in turn requires widespread enough ownership. As a result, the ownership structure of the firm influences the value of market monitoring: a more concentrated ownership decreases liquidity, the informativeness of the stock price, and hence its usefulness in managerial compensation. In this way, the paper highlights a reason for firms to go public beyond the desire to raise capital, namely to improve managerial incentives.

Dewatripont and Tirole (1994b) is a significant contribution to the financial-contracting literature, which aims to explain the capital structure of firms as the outcome of an opti-

[58] Aghion and Tirole (1994) is a related earlier contribution. Tirole has also made several methodological contributions to the theory of incomplete contracts, which we do not discuss here.

mal contracting problem between investors and the entrepreneur or manager. They built on Aghion and Bolton (1992), who had exploited an incomplete-contracting framework (Grossman and Hart, 1986) to explain why investors tend to get state-contingent control rights when company performance is bad. One example is when a firm defaults on its debt, which transfers control to creditors. Dewatripont and Tirole focused on the optimal relationship between control rights and cash-flow rights. They showed that when performance is poor, the party in control should have a cash-flow claim that is concave in performance (such as debt), while when performance is good more control should be transferred to holders of convex cash-flow claims (such as equity). The model is one of the first to explain the coexistence of distinct external sources of financing, such as debt and equity.

6.6 Behavioral Economics

Most of Tirole's work invokes the conventional assumption that people behave rationally and selfishly. But some of it does not. We have already mentioned the central role of altruism and image motives in Lerner and Tirole (2003) and Bénabou and Tirole (2011) and of legacy motives in Maskin and Tirole (2004). Together with Roland Bénabou, Tirole has also made extensive contributions to more basic research on people's motives and beliefs. This area, where economics meets psychology, is usually labeled behavioral economics.[59] Without any doubt, this is an important field with ramifications for many areas of economics. In the future, it may even offer the prospect of true (re)integration of the social sciences. However, it is also a field in which knowledge has had less time to settle, and we therefore do not discuss these contributions here.

7 Conclusion

Jean Tirole's research is characterized by respect for the particulars of different markets and the skillful use of new analytical methods in the economic sciences. He has developed deep analytical results about the essential nature of imperfect competition and contracting under asymmetric information. Tirole has also distilled his own and others' results into a unified framework for teaching, policy advice, and continued research. His contributions provide a splendid example of how economic theory can be of great practical significance.

[59] For example, some of their work has reconsidered the value of powerful material incentives, arguing that such incentives may backfire. One of their explanations is that people who would like to convey their altruism can be deterred by material incentives because others might get the wrong idea about their motives (Bénabou and Tirole, 2006).

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