Legal Institutions, Innovation and Growth*

Luca Anderlini[†] Leonardo Felli[§]
Giovanni Immordino[‡] Alessandro Riboni[¶]

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Abstract

We analyze the relationship between legal institutions, innovation and growth. We compare a rigid legal system (the law is set before the technological innovation) and a flexible one (the law is set after observing the new technology). The flexible system dominates in terms of welfare, amount of innovation and output growth at intermediate stages of technological development — periods when legal change is needed. The rigid system is preferable at early stages of technological development, when commitment problems are severe. For mature technologies the two legal systems are equivalent. We find that rigid legal systems may induce excessive R&D investment.

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[†]Georgetown University, U.S.A

[‡]Università di Salerno, Italy

[§]London School of Economics, U.K.

[¶]École Polytechnique and Université de Montréal, Canada

1 Introduction

Technology and legal rules are bound to coevolve. Early examples of technology that impacted the legal system are steamboats and railroads. They brought up a variety of unprecedented cases and placed novel demands on the law. Steamboats proved risky because of fires and boiler explosions, leading eventually to the responsibility for steamboat owners and captains to prove non negligent behavior in case of litigation (Khan, 2004). Liability rules were also challenged by railroads because of sparks on crop and incredibly numerous injuries and fatalities (Ely, 2001).[1]

We develop here a simple model of endogenous technological change to study the interaction between legal institutions and innovation. On the one hand, quality-improving innovation arises randomly and endogenously: the likelihood is proportional to R&D investments.[2] On the other hand, law makers face a trade-off between providing private firms with the incentives to invest in research (thus increasing the probability that innovation occurs) and protecting the public from the externalities arising from the new technologies.

It is key to our analysis that the law that optimally solves the above trade-off differs according to whether we look at the problem ex-ante (before R&D investments are chosen) or ex-post (when the R&D investments are sunk and after uncertainty has been resolved). This is because at the ex-ante stage the optimal law internalizes the effect on investment decisions – but does not do so at the ex-post stage.

In this setting we compare two benchmark legal regimes. We consider first a flexible legal system where the law can be amended ex post, after a new technology arises. We then consider a rigid regime where the law is written ex-ante and cannot be subsequently changed. We assume that it is hard to accurately describe at the ex-ante stage future contingencies. In the rigid regime the same law has to apply regardless of the technological environment realized.

[1] Other technological advances that also drove legal innovation include medicine (e.g., in vitro fertilization and genetic testing), automobiles, computing, and communication (e.g., telegraphy and, more recently, the internet). See Khan (2004) and Friedman (2002) for a discussion of how the US legal institutions responded to various instances of technological innovation.

[2] In the growth literature, quality-improving innovations are known as "vertical" innovations. See the seminal papers by Aghion and Howitt (1992) and Grossman and Helpman (1991). See instead Romer (1987, 1990) for growth models where innovation is horizontal (i.e., innovators expand the *variety* of available goods).

The reason why we focus on this particular distinction is twofold. First, at least since Posner (1973) flexibility is usually regarded as a key feature that differentiates Common Law from Civil Law.[3] Second, recent empirical work (namely, Beck, Demirguc-Kunt, and Levine 2003) has provided some evidence that the adaptability of Case Law partly explains some of the benefits of Common Law for financial and other variables.[4]

The choice between our two legal systems involves a trade-off between commitment and flexibility. The flexible system does not commit in advance to any rule and optimally determines, at an ex-post stage, the penalties associated with the externalities associated with the new technology. The rigid system, instead, commits ex-ante to a set of penalties for externalities but in so doing it has to impose the same penalties independently on whether the technological innovation occurs or not.

More specifically, in our model a lax regulatory standard may be optimal ex ante because it provides strong incentives to innovate. After innovation has occurred, however, considerations about safety and health may induce law-makers to prefer a stricter regulation. In the absence of commitment on the part of law-makers it then follows that equilibrium R&D investment would be suboptimally low when viewed from an ex ante perspective. The rigid regime does not suffer from commitment problems because law-enforcers are bound to follow the rule that was written ex ante but it might be characterized by inefficiently high externalities.

The trade-off between commitment and flexibility has long been studied in economics. However, we want to emphasize an important point of distinction from the rule-versus-discretion literature. This literature usually assumes that the degree of uncertainty, which is the crucial parameter to evaluate the trade-off, is exogenous.[5] Instead, in this paper the degree of uncertainty

[3]As argued in Beck and Levine (2005), "legal systems that embrace case law and judicial discretion tend to adapt more efficiently to changing conditions than legal systems that adhere rigidly to formalistic procedures and that rely more strictly on judgements based narrowly on statutory law."

[4]Beck, Demirguc-Kunt, and Levine (2003) construct a measure of adaptability of the legal system that takes into account whether judicial decisions are based on previous court decisions and on principles of equity rather than on statutory law. Their measure uses data from Djankov, La Porta, López de Silanes and Shleifer (2003) and La Porta, López-de-Silanes and Shleifer (2004).

[5]For example, Rogoff (1985) compares rigid targeting systems and flexible monetary regimes and argues that rigid regimes are preferable if uncertainty about aggregate productivity shocks is low. More recently, Amador, Werning and Angeletos (2006) study the

(which is related to the speed of technological change) is *endogenous* (via R&D investment) and itself determined by the legal environment.

The assumption that the underlying uncertainty is endogenous has important implications in our model of the rigid regime. For example, consider the problem of a legislator who has to write a single (non-contingent) law before knowing whether or not the current technology will be replaced by a more advanced technology. When the likelihood of discovering the new technology is either very low or very high, the constraint the legislator faces in the rigid regime matters less: in either case, the legislator will simply select the rule that optimally regulates the most likely contingency.[6] Since the probability of replacing the status-quo technology depends on the law that is selected ex ante and since a rigid system has a comparative advantage in a certain environment (where the constraint matters less), the legislator has an incentive to choose a law that reduces the underlying uncertainty in the economy. In particular, the rigid regime may end up selecting a rule that either discourages or, more surprisingly, strongly encourages R&D investment. The result is that the amount of R&D investment in a rigid legal system is either very low or excessive (greater than first-best). Conversely, overinvestment in research never occurs when legal institutions are flexible.

Finally, we argue that the terms of the trade-off between commitment and flexibility are not constant but change over time as technology matures. Consequently, legal institutions that are appropriate at the early stages of technological development may no longer be desirable at later stages.

In particular, rigid legal systems are preferable at the early stages of technological development — these are periods when we expect commitment problems to arise. Indeed, during the early stages of development of a technology, one would expect the relative size of (the change in) externalities to be larger compared to the productivity increase yielded by technological innovation. For instance, productivity gains may be small when a new technology is introduced due to adjustment and learning costs. Since investors correctly foresee that in the flexible regime law-makers will choose strict regulatory standards ex-post, investment in research might be suboptimally low and the inefficient technology more likely to survive.

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optimal trade-off between commitment and flexibility in an intertemporal consumption model with time inconsistent preferences and taste shocks. In both papers the degree of uncertainty is exogenously given.

[6] The legislator understands how the law affects the incentives to innovate and knows the payoff consequences of the law in each technological environment.

Instead, a flexible legal system dominates (in terms of welfare, amount of innovation and output growth) in economies at intermediate stages of technological development. These are periods in which the relative size of productivity gains and variation in externalities is in the intermediate range, and hence the (ex-post) optimal laws under the old and under the new technology may differ a lot. Hence, a single rule is necessarily suboptimal and flexibility has high value. At the same time, commitment has low value because the law that provides incentives to innovate is the same one that law-makers would choose ex post in the new technological environment.

Finally, we show that when technology is mature — variations in externalities are comparatively small — the two legal systems lead to the same economic outcomes because neither commitment nor flexibility is particularly valuable.

The rest of the paper is organized as follows. Section 2 briefly discusses some related literature. In Section 3 we present our model and in Section 4 we characterize the optimal laws in the two legal regimes. Section 5 compares the rigid and flexible regimes. Section 6 concludes. For ease of exposition all proofs are in the Appendix.

2 Related Literature

To the best of our knowledge, Anderlini, Felli, and Riboni (2011) is the first paper to analyze time-inconsistency problems in judicial decision making. That paper considers a model of Case Law in which the judges suffer from an ex-post temptation to be excessively lenient that stems from the fact that all economic decisions are sunk by the time the parties go to court. In that set up, there is a specific role for the rule of precedent (*stare decisis*).

There is a sequence of cases, considered in turn by a sequence of forward-looking courts. Precedents, with some probability, bind the decisions of future courts, thus mitigating their tendency towards excessive leniency. Since each court can affect the state of precedents via its current decision, this creates an incentive for the current court, even though it rules ex-post, to avoid inefficiently lenient decisions. The thrust of Anderlini, Felli, and Riboni (2011) is to characterize the optimal trade-off created by these incentives.

Kaplow (1992) is a fundamental and wide-scoped work on the economics of "rules versus standards" rooted in the scholarly tradition of law. A rule is a law with an ex-ante prescription (it has ex-ante "content") while a standard only acquires “content” ex-post.[7] The back-bone of the analysis in Kaplow (1992) is the study of the trade-offs that (normatively) drive the choice between rules and standards as they apply to the economic sphere. While he explores many variations and extensions of the basic set-up, the main trade-off he identifies is due to the fact that rules are more expensive to formulate ex-ante, while standards are more expensive to interpret (and hence enforce) ex-post. As a result, an important consideration in the choice of a rule versus a standard is the frequency with which it will be invoked, and the heterogeneity of the pool of situations to be considered.

Comin and Hobijn (2009) analyze a model of lobbying and technology adoption and argue that countries where the legislative authorities have more flexibility, the judicial system is not effective, or the regime is not very democratic, new technologies replace old technologies more slowly. This happens because rigidity in lawmaking makes lobbying for protecting the old technology more difficult. The mechanism that explains why in their paper a rigid system may favor technological progress relatively to a flexible system is completely different from ours. In our model, the channel is twofold. First, flexibility may harm technological progress because of time consistency problems. This explains why law-makers in a flexible system may choose ex-post a law that is less favorable to inventors than the one in the first-best solution. Second, for the reasons explained above rigid systems may choose a law that is more favorable to investors compared to the first-best solution.

Similarly to this paper, Acemoglu, Aghion, and Zilibotti (2006) argue that the policies that increase growth in the early stages of development may be suboptimal at later stages. In particular, they formalize the Gerschenkron’s (1962) view that relatively backward economies should pursue an investment-based strategy, which relies on long-term (hence, rigid) relationships between entrepreneurs and financiers and on a less competitive environment. However, as the economy approaches the world technology frontier, they argue that countries should switch to an innovation-based strategy, which requires more short-term (hence, more flexible) relationships, better selection of firms and managers and more competitive policies.

Acemoglu, Antràs, and Helpman (2007) study the relationship between contractual incompleteness, technological complementarities, and technology adoption. In their model, a firm chooses its technology and investment levels

[7] As a example, a rule might prescribe that it is forbidden to drive “over 55 miles per hour,” while a standard would forbid “excessive speed.” See Kaplow (1992), p. 560.

in contractible activities with suppliers of intermediate inputs. Suppliers then choose investments in noncontractible activities, anticipating payoffs from an ex post bargaining game. Their paper argues that greater contractual incompleteness leads to the adoption of less advanced technologies, and that the impact of contractual incompleteness is more pronounced when there is greater complementarity among the intermediate inputs.[8]

Finally, Immordino, Pagano, and Polo (2011) analyze optimal policies when firms' research activity leads to innovations that may be socially harmful. Public intervention, affecting the expected profitability of innovation, may both thwart the incentives to undertake research and guide the use of each innovation. In our setting we abstract from the enforcement problem, and we judge the optimality of a legal system by studying the trade off between its adaptability to technological change and its capacity to provide incentives to innovate.

3 The Model

We consider a stylized model of endogenous technological change where innovation improves the quality of existing products and makes old products obsolete. Our economy includes three sectors: the R&D sector, the intermediate good sector (which is regulated by the law) and the final good sector.

To keep our setting tractable and focus attention on the interaction between legal systems and innovation, our model is simplified along various dimensions: for instance, the input prices in the R&D sector and in the intermediate good sector are assumed to be exogenously given.

3.1 Technology and Market Structure

The final good is produced competitively using a single intermediate good. We let $i \in \{0, 1\}$ denote the quality of the intermediate good.

We assume a standard production technology, namely

$$y(i) = A(i) x(i)^{\frac{1}{2}}, \tag{1}$$

where $x(i)$ is the amount of intermediate good of quality i and $A(i)$ is a

[8]See also Acemoglu (2009, p. 801) for a discussion of the possibility of a hold-up problem in technology adoption.

parameter that measures the productivity of the intermediate good, and $y(i)$ is total output when the quality of the intermediate good is i.[9]

The quality of the intermediate good can take two values: $i = 0, 1$. We assume that quality 0 is less productive than quality 1: that is, $A(1) = \gamma_A A(0)$, with $\gamma_A > 1$.

Crucially, the intermediate good of quality 1 is available only if inventors are successful at discovering it. If R&D investment is not successful, only intermediate good of quality $i = 0$ is produced. More details about the probability of successful innovation will be spelled out in Subsection 3.4 below.[10] In our model, innovation is drastic. In other words, the final good sector demands only the most productive technology available.[11]

The intermediate good is produced by a monopolist using inelastically supplied labor. Production is regulated by law. Specifically, regulation requires the firm to comply with the law in the use of inputs. As a result, regulation affects the cost of production.

To keep things tractable, assume that the marginal cost of the intermediate good firm is constant and equal to

$$MC(a) = \frac{1}{a}, \tag{2}$$

where $a \in [\underline{a}, \overline{a}]$ is an index related to the degree of regulatory strictness embodied in the law. We assume $\overline{a} > \underline{a} > 0$. For instance, a can be thought as the inverse of the level of caution required in the production process.

[9] Our notation is convenient, but we point out that it contains a slight abuse. While $x(i)$ indicates quantities of two different physical goods as $i \in \{0, 1\}$ varies, total output always consists of the same physical final consumption good. Indexing output by $i \in \{0, 1\}$ is useful in the sequel since it allows us to keep track of differences in output in the two possible "technological states" that our model allows. Notice also that, from (1), the output elasticity with respect to $x(i)$ is 1/2. Under this assumption, the indirect utility of the representative agent in the economy has a very simple form (see Subsection 4.1 below). This will allow us to obtain closed form solutions in the two legal regimes. The main thrust of our results, however, would not change in a more general specification.

[10] In Anderlini, Felli, Immordino, and Riboni (2011) we considered a dynamic extension of this model where the number of innovations is potentially infinite. Results in the dynamic model are, however, very similar to the ones discussed here in a simple setting with only two technological states.

[11] Innovation is non-drastic if and only if the firm that uses the status-quo technology can make positive profits when the firm that produces the most advanced technology is charging the monopolistic price. As in Aghion and Howitt (1992) (Section V) innovations are drastic if γ_A is sufficiently high.

According to this interpretation, when a is high, it means that the firm is not required to be very cautious and, consequently, its marginal cost is low.[12]

The price of the intermediate good relatively to the final good is denoted by $p(i)$.

3.2 Preferences

The utility of the representative agent in this economy is[13]

$$u\left(c(i), a; i\right) = c(i) - \lambda\left(i\right) a. \tag{3}$$

Utility depends linearly on the consumption of the final good $c(i)$. Moreover, we assume that the lack of caution in the production of the intermediate good generates a negative externality affecting the consumer. Notice that this externality is reduced if the intermediate good firm is more cautious (that is, a is low). The severity of the externality depends on the quality of the intermediate good used in production and is parameterized by $\lambda\left(i\right)$. We assume that $\lambda\left(1\right) = \gamma_{\lambda}\lambda\left(0\right)$ where $\gamma_{\lambda} \geqslant 0$. For simplicity, we normalize $\lambda\left(0\right)$ to 1.[14]

As a motivation for the preferences in (3) consider the case where the final good is produced with genetically modified ingredients which may cause environmental and health externalities. The emissions of sparks and cinder caused by railroads is another classic example of externality that has been dealt with by the legal system.[15]

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[12] We also assume that the law can be perfectly enforced. We abstract from the enforcement issue in the belief that the type of legal regime has little impact on it.

[13] Indexing consumption by $i \in \{0, 1\}$ is a mild abuse of notation in exactly the same way as indexing total output. Consumption always consists of the same physical final consumption good. See footnote 9 above. We proceed in this way since it proves convenient in what follows.

[14] If $\gamma_{\lambda} > 1$, the consumer faces a more dangerous innovation. In this case, the innovation makes it more costly for the consumer to have a more permissive legislation. If instead $0 \leqslant \gamma_{\lambda} < 1$, the negative externality from production is less severe under the new technology.

[15] At the end of the 19th century, for instance, typical allegations of negligence included the failure to have a functioning spark arrester, to use the appropriate type of fuel, to keep the roadway free of weeds, or the failure to build fire guards on the edge of the roadway. See Grady (1988) and Ely (2001) for an account of early cases concerned with these issues.

3.3 The Maximization Problem of the Intermediate Good Firm

We denote by $\Pi(a,i)$ the profit function of the monopolist that produces the intermediate good of quality i,

$$\Pi(a,i) = \max_{x(i)\geq 0} \left[p(i) - \frac{1}{a} \right] x(i), \tag{4}$$

where a reflects the law enforced in state i. Since the final-good producer is competitive, the inverse demand of the intermediate good is

$$p(i) = \frac{1}{2} A(i)\, x(i)^{-\frac{1}{2}}. \tag{5}$$

That is, $p(i)$ is equal to the marginal product of the intermediate good. The monopolist's production choice is then

$$x(i) = \left[\frac{A(i)\, a}{4} \right]^2. \tag{6}$$

Substituting equation (6) into (4) we obtain

$$\Pi(a,i) = a\phi(i), \tag{7}$$

where

$$\phi(i) \equiv \left[\frac{A(i)}{4} \right]^2. \tag{8}$$

Clearly, from (7), profits in the intermediate good sector are increasing in a.

3.4 Optimal Investment in Research

The R&D sector includes one firm which chooses the amount of research investment, denoted by z, aimed at discovering technology 1. When z is the investment, innovation arrives randomly with probability

$$Pr\, \{innovation\} = \iota + \theta z, \tag{9}$$

where $\iota \in [0,1]$ and $\theta \geq 0$.[16] With complementary probability, the R&D firm does not succeed in innovating and technology 0 is not replaced.

[16] Given ι and θ, $\overline{z}$ denotes the level of investment such that $\iota + \theta z = 1$. Throughout, we assume that $z \in [0, \overline{z}]$.

The probability of a successful innovation, from equation (9), has two components: an exogenous component and an endogenous component which depends on z. In this paper, we focus on two benchmark cases. In Subsection 5.1 below we analyze the case where $\theta = 0$, that is the probability of a successful innovation is exogenous. In Subsection 5.2 instead, we analyze the opposite case where $\iota = 0$.

In case R&D investment is successful, the patent of the new technology is sold to a firm which is willing to produce the intermediate good using technology 1. We assume that the R&D firm extracts all the surplus: it sells the patent at a price equal to $\Pi(a, 1)$.

Research is a costly activity. For tractability, we take the cost to be quadratic. The R&D firm chooses the amount of research expenditure that maximizes expected profits. That is, investment in R&D solves

$$\max_{z \in [0, \overline{z}]} (\iota + \theta z) \Pi(a, 1) - \frac{1}{2} z^2. \tag{10}$$

Assuming an interior solution and using (7) the first-order condition of problem (10) gives us

$$z = \theta a \phi(1). \tag{11}$$

Expression (11) highlights the mechanism through which the law affects the probability of a successful innovation in our model. A pro-business law (high a) increases the profits of the intermediate good firm, raises the price of a patent and makes R&D investment more profitable, thereby increasing the probability of discovering the more productive technology.[17]

It is important to notice that in order to determine the optimal amount of R&D investment what matters is the law the R&D firm expects will prevail under technology 1. The law that is enforced under the status-quo technology does not affect the decisions of the R&D firm.[18]

[17] The importance of the legal and regulatory frameworks on investment (and innovation) strongly emerges from the Investment Climate Surveys recently launched by the World Bank. See Gray (1987) for an empirical analysis of the negative consequences of regulation on productivity in the US manufacturing industry.

[18] In principle, the lawmakers could improve the incentives for innovation with R&D subsidies rather than controlling the externality. However, due to informational asymmetries (with firms knowing payoffs to innovation much more accurately than the Government) it seems unlikely that subsidies could go all the way in solving the problem. We are grateful to one of the referees for emphasizing this point to us.

4 Optimal Laws

In this section we derive the optimal laws (the levels of a) under two different legal regimes. As discussed above, a can be interpreted as an inverse index of regulatory strictness embodied in the law. Law-makers are benevolent in the sense that they choose the law in order to maximize the utility of the representative consumer. The two legal regimes differ in the timing of the law-maker's optimal choice of a. In particular, we distinguish between the *flexible* legal regime (denoted by $\mathcal{F}$), where the law-maker chooses a after observing the technological state i, and the *rigid* legal regime (denoted by $\mathcal{C}$), where the law-maker chooses a before observing the technological state i (and this choice cannot be contingent on i).

4.1 Ex-Post Optimal Laws

Consider, first, the *flexible* legal regime $\mathcal{F}$. Under this regime the timing is as follows. First, the R&D firm chooses how much to invest. In making this choice, it correctly foresees what law-makers will choose ex-post. Investment is either a success or a failure. Law-makers observe the current technological state and choose the law. Finally, production and consumption take place.

In order to solve the legislator's problem we derive the indirect utility of the representative consumer in each technological environment.

Using (1), (3), (6) and the equilibrium condition $c(i) = y(i)$, we obtain that the indirect utility in state i is linear in a:

$$u(a, i) = a\vartheta(i), \tag{12}$$

where

$$\vartheta(i) \equiv \frac{1}{4}A(i)^2 - \lambda(i) \tag{13}$$

From (12) an increase of a has two effects on utility. First, it has a direct (negative) effect due to the externality it creates. The higher $\lambda(i)$, the higher is this effect. Second, a higher a decreases the marginal cost of the intermediate good producer and increases the production of the final good. A more pro-business law has then an indirect (and positive) effect on utility because consumption increases. The higher $A(i)$, the higher the marginal benefit of increasing a due to this second effect.

Throughout the paper we assume that innovation, besides increasing the productivity of the intermediate good, is welfare-improving.[19]

Assumption 1 *Innovation increases consumer utility:* $\vartheta(1) > \vartheta(0)$.

We let a_i^{ep} denote the law $a \in [\underline{a}, \overline{a}]$ that maximizes (12). Throughout the paper, we refer to a_i^{ep} as the *ex-post optimal law* in state i. This is the law that law-makers would choose ex-post: after the technological environment i is observed.[20]

Therefore, in the flexible legal regime law-makers in state i choose a_i^{ep}. Any other law would not be sequentially optimal. Using (11), expected welfare in the flexible regime can then be written as:

$$W_{\mathcal{F}} = \left[\theta^2 \phi(1) a_1^{ep}\right] a_1^{ep} \vartheta(1) + \left[1 - \theta^2 \phi(1) a_1^{ep}\right] a_0^{ep} \vartheta(0). \tag{14}$$

Given the linearity of (12), it is straightforward to see that

$$a_i^{ep} = \begin{cases} \overline{a} & \text{if} \quad \vartheta(i) \geqslant 0, \\ \underline{a} & \text{if} \quad \vartheta(i) < 0. \end{cases} \tag{15}$$

From (13) notice that the ex-post optimal law will be punitive for the intermediate good firm (that is, equal to $\underline{a}$) when the productivity of the intermediate good $A(i)$ is relatively low compared to the externality $\lambda(i)$. One would expect this configuration of parameters (namely, low productivity and severe externality) to occur in the early stages of the life cycle of several technologies.[21] As technologies develop, however, we expect productivity to increase and the negative externality on consumers to matter less. In such a case, the ex-post optimal law will be a pro-business law (that is, $\overline{a}$).

Clearly, from (13), if $A(0)$ is sufficiently low relatively to $\lambda(0)$, both $\vartheta(0)$ and $\vartheta(1)$ are negative. Then, from (15), both a_0^{ep} and a_1^{ep} are equal to $\underline{a}$. When instead the productivity of the status-quo technology is relatively

[19] It is possible to show that the result in Proposition 2 is reversed when the innovation is welfare decreasing.

[20] As we will see in Section 5, this law not necessarily coincide with the law that law-makers would choose ex-ante: before observing the technological environment i.

[21] For instance, it is generally assumed that most general purpose technologies (such as, steam, electricity, and information technology) deliver low productivity gains immediately upon their adoption. The presumption is that several adjustment and learning costs may cause output to initially fall when a general purpose technology arrives. See Jovanovic and Rousseau (2005).

high, $\vartheta(0)$ and $\vartheta(1)$ are both positive and a_0^{ep} and a_1^{ep} are equal to $\overline{a}$. A feature common to both cases is that the ex-post optimal laws under the two technologies coincide. Finally, when the starting value of $A(0)$ belongs to an intermediate range, we have that $\vartheta(0)$ is negative but that $\vartheta(1)$ is positive. The ex-post optimal law before and after technological change differ and $a_0^{ep} = \underline{a}$ while $a_1^{ep} = \overline{a}$.

We can, therefore, postulate the following classification.

Definition 1 *Technology is at an* <u>*early stage*</u> *of development when* $\vartheta(0) < \vartheta(1) < 0$. *This occurs when the productivity of the status-quo technology is sufficiently low:*

$$A(0) < \frac{2\sqrt{\gamma_\lambda}}{\gamma_A}. \tag{16}$$

Technology is at an <u>*intermediate stage*</u> *of development when* $\vartheta(1) \geqslant 0 > \vartheta(0)$ *or, equivalently, when*

$$\frac{2\sqrt{\gamma_\lambda}}{\gamma_A} \leqslant A(0) < 2. \tag{17}$$

Finally, technology is <u>*mature*</u> *when* $\vartheta(1) > \vartheta(0) \geqslant 0$. *This occurs when*

$$A(0) \geqslant 2. \tag{18}$$

It is then immediate to verify that at an early stage $a_0^{ep} = a_1^{ep} = \underline{a}$. This implies that at this stage of technological development the ex-post optimal law under technology 1 provides weak incentives to invest in R&D. We interpret this as a situation where commitment problems are potentially severe. At an intermediate stage we have instead $a_0^{ep} = \underline{a}$ and $a_1^{ep} = \overline{a}$. Finally, at an advanced stage, $a_0^{ep} = a_1^{ep} = \overline{a}$.

4.2 Ex-Ante Optimal Law

Consider next the *rigid* regime $\mathcal{C}$. In this regime the law is chosen ex-ante before observing the technological state i. As mentioned above, we crucially assume that in the rigid regime, the law cannot be made contingent on the technological environment. This is because at the ex-ante stage the two environments are impossible to describe in their full details.[22] Let $a_\mathcal{C}$ denote the law that will be enforced under both technologies in the $\mathcal{C}$ regime.

[22]However, as is standard in the incomplete contracting literature (e.g., Grossman and Hart, 1986, and Hart and Moore, 1990), we also assume that law-makers understand how

The timing is then the following. First, the legislator chooses a single law in order to maximize the expected utility of the representative agent. In other words, $a_{\mathcal{C}}$ is the solution to the following problem:

$$\max_{a\in[\underline{a},\overline{a}]} \left[\theta^2\phi(1)a\right] a\vartheta(1) + \left[1-\theta^2\phi(1)a\right] a\vartheta(0). \tag{19}$$

After $a_{\mathcal{C}}$ is selected, the R&D firm chooses the investment level. Investment results either in a success or a failure. Regardless of the current state of the technology, law-makers are bound to enforce ex-post the law that was chosen ex-ante. Therefore, the intermediate good firm exerts caution in the choice of the amount $a_{\mathcal{C}}$. Finally, the production of the intermediate good and of the final good take place.

In contrast to the flexible regime, from (19), ex-ante the law has an additional effect on consumers' utility, besides the ones discussed in Subsection 4.1, since it affects the probabilities of the two technological states. This is why the ex ante optimal law may not coincide with the law that law-makers would choose ex-post, when R&D investment has been chosen and the uncertainty about the technology has been resolved.

The expected welfare in the rigid regime is then

$$W_{\mathcal{C}} = \left[\theta^2\phi(1)a_{\mathcal{C}}\right] a_{\mathcal{C}}\vartheta(1) + \left[1-\theta^2\phi(1)a_{\mathcal{C}}\right] a_{\mathcal{C}}\vartheta(0). \tag{20}$$

5 Commitment vs. Flexibility

In general, and for different reasons, the two legal systems that we have just described are both bounded away from efficiency. On the one hand, the flexible regime is adaptable but it lacks commitment. As a result, it may not provide sufficient incentives to innovate. On the other hand, in the rigid regime the law-maker is able to commit but is bound to choose a single law and, consequently, he cannot adapt to changing conditions. The incompleteness of the law is then the source of inefficiency of the rigid regime.

In this section we compare our two legal regimes. We do this under two distinct assumptions on the probability of a successful innovation.

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the law affects the probability of successful innovation and know the payoff consequences of the law in the two technological states. For a model of an event that is not describable but fully understood by the parties involved ex-ante see Al-Najjar, Anderlini, and Felli (2006).

5.1 Exogenous Innovation

Consider, first, the benchmark case where $\theta = 0$. Since the probability of successful innovation is not affected by z, the solution to problem (10) is obviously to choose $z = 0$. Using (9) the probability that innovation occurs is then exogenously given and equal to ι.

Since the law cannot provide incentives to innovate, legal systems differ only with respect to their ability to choose the best law for each technology. Given this premise, it is entirely straightforward to conclude that when innovation is exogenous the flexible regime weakly dominates the rigid one.

Proposition 1 (Exogenous Innovation) *Suppose that $\theta = 0$ so that innovation is entirely exogenous. Then,*

(i) When technology is either at an early stage or is mature, the flexible and rigid regimes achieve the same welfare.

(ii) When instead technology is at an intermediate stage, the flexible regime weakly dominates the rigid one.

The first statement of Proposition 1 is straightforward. The two regimes achieve equivalent welfare levels when the ex-post optimal laws are the same under both technologies.[23] This occurs because the incompleteness constraint, which forces the legislator in the rigid regime to choose a single law for both states, is not binding.

The second statement of Proposition 1 follows directly from the computation of $W_{\mathcal{F}}$ and $W_{\mathcal{C}}$ when technology is at an intermediate stage.

Knowing that in the flexible regime law-makers choose the ex-post optimal laws as in (15), we have

$$W_{\mathcal{F}} = \iota \overline{a} \vartheta(1) + (1 - \iota) \underline{a} \vartheta(0). \tag{21}$$

Consider now the rigid regime. The legislator chooses $\underline{a}$ (resp. $\overline{a}$) when ι is below (resp. above) a given threshold

$$\overline{\iota} = \frac{(\underline{a} - \overline{a})\, \vartheta(0)}{(\overline{a} - \underline{a})\, (\vartheta(1) - \vartheta(0))}. \tag{22}$$

[23] From Definition 1, this possibility arises when the economy is either at an early or at an advanced stage of development.

Indeed, the legislator must choose a single (non-contingent) law. Therefore, the chosen law is the one that better regulates technology 0 if and only if successful innovation is not very likely. We then obtain

$$W_{\mathcal{C}} = \begin{cases} \iota \underline{a}\vartheta(1) + (1-\iota)\underline{a}\vartheta(0) & \text{if} \quad \iota \leqslant \bar{\iota} \\ \iota \overline{a}\vartheta(1) + (1-\iota)\overline{a}\vartheta(0) & \text{otherwise.} \end{cases} \tag{23}$$

In Figure 1 below, we draw (21) and (23). Both $W_{\mathcal{F}}$ and $W_{\mathcal{C}}$ are increasing in ι by Assumption 1. Moreover, $W_{\mathcal{C}}$ has a kink at $\bar{\iota}$. It is important to notice that the welfare loss of the rigid regime *vis-à-vis* the flexible regime is zero when there is no uncertainty. Conversely, for intermediate values of ι it is relatively more costly to have an non-contingent law. In other terms, in this region of parameters the Lagrange multiplier associated with the incompleteness constraint is high.

[**Figure 1**]

5.2 Endogenous Innovation

We now consider the case in which the probability of a successful innovation is fully endogenous: that is, $\theta > 0$ and $\iota = 0$. When $\theta > 0$, the optimal amount of R&D investment is positive and is endogenous to the model. Since investment now depends on the law, credibility problems potentially arise. This is because at the ex-ante stage law-makers do take into account the effect of the law on the incentives to invest — see (11) above — but do not do so at the ex-post stage.

An implication of our analysis is that the legislator in the rigid regime may have an incentive to select a rule that reduces the underlying uncertainty in the economy. As shown below, this result can be achieved by either strongly encouraging or strongly discouraging R&D investment.

From (19), the optimal law in the rigid regime $a_{\mathcal{C}}$ solves

$$\max_{a \in [\underline{a}, \overline{a}]} \vartheta(0)\, a + \theta^2 \phi(1) a^2 \left[\vartheta(1) - \vartheta(0)\right]. \tag{24}$$

Since by Assumption 1 we have $\vartheta(1) - \vartheta(0) > 0$, the objective function is convex in the law. This implies that (24) yields a bang-bang solution: the chosen law $a_{\mathcal{C}}$ is either $\underline{a}$ or $\overline{a}$. As a result, the probability of discovering the new technology is either the lowest or the highest possible one. More precisely, we obtain

$$a_{\mathcal{C}} = \begin{cases} \overline{a} & \text{if} \quad \dfrac{\vartheta(0)}{\vartheta(1) - \vartheta(0)} + \theta^2 \phi(1)(\overline{a} + \underline{a}) \geqslant 0, \\ \underline{a} & \text{otherwise.} \end{cases} \tag{25}$$

We can now identify the optimal law chosen by the legislator in each of the three stages of technological development.

Mature stage. Recall that in the mature stage the parameters are such that $\vartheta(0)$ and $\vartheta(1)$ are both positive, using (25), we then obtain $a_{\mathcal{C}} = \overline{a}$. This result is intuitive: selecting law $\overline{a}$ provides the right incentive to conduct research and, at the same time, it optimally regulates the two technological environments we may observe ex post.

Intermediate Stage. When technology is at an intermediate stage, the law that fosters innovation, namely $\overline{a}$, is ex-post optimal when innovation is successful but is suboptimal when innovation is not successful. From (25), the legislator chooses $\underline{a}$ when the difference between $\vartheta(1)$ and $\vartheta(0)$ is small and, consequently, it is not valuable to provide incentives to innovate. Law $\underline{a}$ is also selected when $\vartheta(0)$ is extremely low. In this case, it would be very costly to enforce $\overline{a}$ in case innovation does not succeed. Finally, if the probability of a successful innovation can be made sufficiently close to 1 (that is, θ and $\phi(i)$ are high), then the choice $\overline{a}$ dominates.

[Figure 2]

Early Stage. In this environment providing incentives to conduct research (choosing $\overline{a}$) is suboptimal when R&D investment fails but also when it succeeds. However, (25) implies that in some cases the legislator does select $\overline{a}$. To understand why consider Figure 2 above. It depicts the indirect utility of the representative consumer – see definition (12) above – for both technological states. Given that at this stage $\vartheta(0)$ and $\vartheta(1)$ are negative, both indirect utilities are decreasing in a. Points A and B (resp. points C and D) identify the agent's utility associated to law $\underline{a}$ (resp. $\overline{a}$) in state 1 and 0.[24] Since at an early stage we have that in both states law $\underline{a}$ is ex-post optimal, from a welfare view point A dominates C and B dominates D. However, to see why the legislator may sometimes choose $\overline{a}$ notice that the weights in the ex-ante utility (20) are endogenous. When the choice of $\overline{a}$ raises the probability of state 1 by a considerable amount, the weighted sum of A and B may be smaller than the weighted sum of C and D.

[24] That is, $A = (\underline{a}, \vartheta(1))$, $B = (\underline{a}, \vartheta(0))$, $C = (\overline{a}, \vartheta(1))$ and $D = (\overline{a}, \vartheta(0))$.

Finally, looking at Figure 2 again, notice that providing incentives to innovate (that is, choosing law $\overline{a}$) is particularly inefficient when innovation does not occur. This explains why the objective function in (24) is convex in the law and, as a result, the legislator in the rigid regime may either strongly encourage or strongly discourage R&D investment.

We are now ready to compare the two legal institutions. Proposition 2 below establishes that, in contrast to Section 5.1, when R&D investment is endogenous the flexible regime is not necessarily optimal in all cases.

In particular, when technology is at an early stage we have that the rigid regime may actually dominate the flexible regime because of its ability to provide better incentives to innovate. Indeed, at an early stage of technological development the flexible regime selects a law that protects public safety and provides weak incentives to innovate. By choosing $a_{\mathcal{C}} = \underline{a}$ the legislator in the rigid regime can achieve the same welfare that is obtained in the flexible regime. However, in the rigid regime it is also possible to commit to a law greater than $\underline{a}$ in order to provide incentives to innovate. This possibility is not available in the flexible regime and this explains why the commitment regime weakly dominates the flexible one.

When technology is mature, the two systems yield the same outcomes. This is because at this stage the ex-post optimal law is the same under both states (hence flexibility is not valued) and is equal to $\overline{a}$ (hence, commitment is equally not valued). Finally, in economies at intermediate stages of development — periods when legal change is needed and there are no commitment problems — the flexible regime is strictly better than the rigid one because of its ability to penalize externalities if innovation fails.

We conclude by computing the rate of output growth. Recall that with probability $1-\theta z$, where z is given in (11), the R&D firm fails to innovate and the rate of output growth is equal to zero. With complementary probability, the growth rate of output is

$$g = \left[\frac{y\,(1) - y\,(0)}{y\,(0)} \right]. \tag{26}$$

Let $E(g_i)$, with $i = \mathcal{F}, \mathcal{C}$, denote the expected rate of output growth under legal regime i. Using (1), (6), (11) and (26) we obtain

$$E(g_{\mathcal{C}}) = \left(\gamma_A^2 - 1\right)\theta^2 \phi(1) a_{\mathcal{C}} \tag{27}$$

and

$$E(g_{\mathcal{F}}) = (\gamma_A^2 \frac{a_1^{ep}}{a_0^{ep}} - 1)\theta^2 \phi(1) a_1^{ep}. \tag{28}$$

The following proposition summarizes our main result.[25]

Proposition 2 (Endogenous Innovation) *Suppose that $\iota = 0$ and $\theta > 0$, so that innovation is entirely endogenous. Then,*

(i) When technology is at an early stage of development, we have that

$$W_{\mathcal{C}} \geqslant W_{\mathcal{F}}, \qquad E(g_{\mathcal{C}}) \geqslant E(g_{\mathcal{F}}).$$

(ii) When technology is at an intermediate stage of development, we have that

$$W_{\mathcal{C}} < W_{\mathcal{F}}, \qquad E(g_{\mathcal{C}}) < E(g_{\mathcal{F}}).$$

(iii) When technology is mature, we have that

$$W_{\mathcal{C}} = W_{\mathcal{F}}, \qquad E(g_{\mathcal{C}}) = E(g_{\mathcal{F}}).$$

It is natural to ask what happens if Proposition 2 is taken to the data. Of course, we can take the assertions of Proposition 2 either as normative prescriptions or as positive predictions. In the former case, if reality does not correspond to the "optimal regime" identified by Proposition 2, then it yields a policy prescription. If on the other hand we think of Proposition 2 as a positive prediction tool, a discrepancy between reality and the "optimal regime" should be considered an indictment of the model.

Our position is that, as in many other instances, our model is too simple to be considered a positive prediction tool, and hence the normative flavor of Proposition 2 is what takes precedence in our view.

An empirical investigation is clearly beyond the scope of the present paper. However, we pause to point out that such an empirical analysis would have to overcome several challenging obstacles. To begin with, one would need cross-country historical data on technological innovation. Moreover, in order to empirically distinguish among the three stages of technological development envisaged here, one would need measures of (possibly, industry-level)

[25] While we strongly believe that innovations are generally welfare increasing, it is possible to show that our main result in Proposition 2 is reversed when the innovation is welfare decreasing. Specifically, (i) when technology is at an early stage of development, we have that $W_{\mathcal{F}} = W_{\mathcal{C}}$; (ii) when technology is at an intermediate stage of development, we have that $W_{\mathcal{F}} > W_{\mathcal{C}}$; (iii) when technology is mature, we have that $W_{\mathcal{C}} \geq W_{\mathcal{F}}$ (the proof is available upon request).

productivity and also measures of the relative size of externalities versus productivity gains caused by technological innovation.[26]

5.3 Rigidity and Overinvestment

We now derive the optimal law in the *first-best* environment. Similarly to the flexible regime, the first-best law specifies a law for each state and, similarly to the rigid regime, the first-best law is specified at the ex ante stage under full commitment. Let a_i denote the law in state $i = 0, 1$. The first-best solution, denoted by (a_0^{fb}, a_1^{fb}), solves

$$\max_{a_0, a_1 \in [\underline{a}, \overline{a}]} \left[\theta^2 \phi(1) a_1\right] a_1 \vartheta(1) + \left[1 - \theta^2 \phi(1) a_1\right] a_0 \vartheta(0). \tag{29}$$

To compute a_0^{fb} notice that a_0 does not affect the amount of R&D investment. Then, we easily obtain

$$a_0^{fb} = \begin{cases} \overline{a} & \text{if} \quad \vartheta(0) \geq 0, \\ \underline{a} & \text{if} \quad \vartheta(0) < 0. \end{cases} \tag{30}$$

We now derive a_1^{fb}. It is immediate to verify that when technology is either at an intermediate or mature stage, $a_1^{fb} = \overline{a}$. When instead technology is at an early stage the objective function in (29) is concave in a_1. Specifically, we obtain

$$a_1^{fb} = \begin{cases} \overline{a} & \text{if} \quad 2\overline{a}\vartheta(1) - \underline{a}\vartheta(0) \geq 0, \\ \underline{a} & \text{if} \quad 2\vartheta(1) - \vartheta(0) \leq 0, \\ (\underline{a}\, \vartheta(0))/(2\vartheta(1)) & \text{otherwise.} \end{cases} \tag{31}$$

How does the amount of R&D investment in the rigid regime compare to the one in the first-best? As we anticipated, in the rigid legal regime we may have either overinvestment or underinvestment in R&D compared to the first-best.[27]

[26] A useful starting point might be the dataset on technology adoption compiled by Comin and Hobijin (2004). They classify technologies according to whether they have a previous competing technology. Whether or not a technology has a predecessor that may be related to its stage of development.

[27] From (11) note that we have overinvestment (resp. underinvestment) in R&D when $a_{\mathcal{C}} = \overline{a}$ while $a_1^{fb} < \overline{a}$ (resp. $a_{\mathcal{C}} = \underline{a}$ while $a_1^{fb} > \underline{a}$). Usually, the literature on incomplete

Proposition 3 (Underinvestment and Overinvestment) *The amount of R&D investment in the flexible regime is always smaller than or equal to the first-best amount. In the early stage of technological development, economies adopting the rigid regime may invest more than first-best.*

To understand why at the early stage we may observe overinvestment, notice that two distinct forces push the legislator in the rigid regime to choose a pro-business law: the implied increase in the probability of a welfare improving innovation and the implied reduction in the probability of a status-quo technology subject to inefficient regulation. Indeed, at an early stage of development a high value of a is always ex post suboptimal but is relatively more inefficient under the old than under the new technology (see Figure 2 above). In the first-best world, the second force is absent since the law is state-contingent and, hence, it is possible to optimally regulate the status-quo technology. This is why the rigid legal system may trigger overinvestment in R&D. Finally, notice that when technology is not at an early stage of development (hence, $\vartheta(1) \geqslant 0$) we obtained $a_1^{fb} = \overline{a}$. Then, it is not possible to observe $a_{\mathcal{C}} > a_1^{fb}$.

At first glance, it may seem paradoxical that the probability of a welfare improving innovation in the rigid regime may be inefficiently high. However, recall that welfare depends on the consumption of the final good but also on the externality. A large investment in R&D may be suboptimal when it is obtained by committing to a high a, which implies a high level of the externality generated in the intermediate good sector.

Comparing (15) with (30) and (31), it is immediate to see that in the flexible legal regime R&D investment is never inefficiently high.

5.4 Costly Change of the Law

We now consider a partially rigid regime where the law can be changed ex post by incurring a strictly positive cost κ. Let $W(\kappa)$ denote optimal welfare in this regime. Clearly, $W(\infty) = W_{\mathcal{C}}$ and $W(0) = W_{\mathcal{F}}$ where $W_{\mathcal{C}}$ and $W_{\mathcal{F}}$ have been defined in (20) and (14) above, respectively.

contracts has focused on the possibility of underinvestment due to ex-post exploitation (see Grout, 1984). The overinvestment result is also obtained in the incomplete contract literature: see for instance, Chung (1995). The underlying reason is different from ours: in that literature, some parties may overinvest to strategically affect their bargaining power ex-post.

The timing is as follows. The legislator, in the partial commitment regime, selects a single law, denoted by $a_{\mathcal{PC}}$. The R&D firm chooses the amount of research investment. In making this decision the R&D firm understands the legislator's incentives to change the law ex-post and choose a_i^{ep} in state i. After knowing whether or not R&D investment was successful, the legislator decides whether to enforce the existing law $a_{\mathcal{PC}}$ or to change it by incurring the cost κ. Given that state i is realized, the legislator changes the law if and only if

$$\vartheta(i)\, a_{\mathcal{PC}} \leqslant -\kappa + \vartheta(i)\, a_i^{ep}. \qquad (32)$$

Finally, production and consumption take place.

The following result analyzes welfare in the regime with partial commitment.

Proposition 4 (Costly Change) *Let any $\kappa > 0$ be given. Then,*

(i) When technology is at an early stage of development, we have that

$$W(\kappa) \geqslant W_{\mathcal{F}}.$$

(ii) When technology is at an intermediate stage of development, we have that

$$W_{\mathcal{C}} \leq W(\kappa) < W_{\mathcal{F}}.$$

(iii) When technology is mature, we have that

$$W(\kappa) = W_{\mathcal{C}} = W_{\mathcal{F}}.$$

The possibility of changing the law ex post is useless when the technology is at an advanced stage of development. When technology is at an intermediate stage of development, flexibility is needed and a pro-business law is also credible. It is then preferable to have a low κ. As long as κ is strictly positive, however, the flexible regime remains superior. In an early stage of development, the partially rigid regime dominates the flexible regime because it has the possibility of reproducing the flexible regime (by choosing $\underline{a}$) and, at the same time, it allows some (limited) commitment.

Before concluding this section, it is interesting to note that at an early stage of technological development, partial commitment ($0 < \kappa < \infty$) is – at least for some parameter values – strictly preferable to having full commitment ($\kappa = \infty$) or full flexibility ($\kappa = 0$).

To understand why this is the case, assume that in the commitment regime the parameters in (25) are such that the optimal law in the fully rigid regime is $\overline{a}$. Moreover, choose a κ that satisfies the following two inequalities:

$$\vartheta(0)\,\overline{a} < -\kappa + \vartheta(0)\,\underline{a}, \tag{33}$$

$$\vartheta(1)\,\overline{a} \geqslant -\kappa + \vartheta(1)\,\underline{a}. \tag{34}$$

Referring to Figure 2 above, it is easy to see that such a κ always exists.[28] Notice from (34) that our partially rigid regime provides credible incentives to innovate since $\overline{a}$ is not changed ex-post in state 1. Moreover, given that κ satisfies (33), the law $\overline{a}$ will be changed ex-post in the case the technological innovation fails. This indicates that an intermediate value of k satisfying (33) and (34) provides flexibility (at a cost) and also commitment.

5.5 Common Law vs Civil Law

Throughout this paper, we have focused on two stylized (and abstract) legal regimes. As discussed in the Introduction the motivation behind the choice of these regimes, however, is the important comparison between Civil and Common Law, the two major legal traditions of the western world.[29]

The parallel is tempting since flexibility is regarded by many as a key feature that differentiates the Common Law from Civil Law.[30]

According to traditional comparative law doctrine, Civil law is a codified system, where the role of Courts is to apply a written body of statutes which can only be amended by the legislature. Since the process of legislative amendment is necessarily slow, this may result in the Civil law being at least partially rigid.

By contrast, Common Law is mostly a judge-made law. That is, the law is, at least in part, established by judicial precedents and decisions. Since

[28] This is because $B - D > A - C$.

[29] A large and influential body of empirical literature known as "Law and Finance" examines the relative performance of Common and Civil Law on various economic outcomes. See the survey of La Porta, López-de-Silanes, and Shleifer (2008).

[30] Lamoreaux and Rosenthal (2005) challenge the view that Common Law is more flexible and show that US Law during the nineteenth century was neither more flexible nor more responsive than French law to the businesses needs.

courts are afforded with greater discretion, law may then evolve gradually and incrementally as judges extend and adapt existing legal principles to new circumstances.

Therefore, we would like to interpret the comparison presented above as a way to identify the forces at play when considering technological innovations under a Common Law, respectively a Civil Law, legal system.

Before concluding this section, two caveats bear mentioning. First, under Common Law the body of statutes has expanded dramatically through time (Calabresi, 1982) and, at the same time, the latitude of civil-law judges in interpreting the statutes has increased (Merryman, 1985). The convergence between the two legal traditions makes "pure" forms of either system hard to identify. Second, in modeling the flexible legal regime we abstract from the precedent-setting value of current decisions, a feature of Common Law. One justification for this omission is that the rule of precedent does not generally apply to regulatory agencies, which deal with many of the legal challenges brought up by technological change. In the US this was established by an important Supreme Court decision which ruled that an agency may change its previous interpretation of an ambiguous statute without settling the statute's meaning.[31]

6 Conclusion

This paper investigates whether a flexible legal system is preferable to a rigid system in keeping up with technological progress. To answer this question we developed a simple model of endogenous technological change where innovations are vertical (new products provide greater quality and replace existing ones) and we analyze the two legal regimes.

We argue that the comparison between the two legal institutions involves a trade-off between commitment and flexibility. In this paper, this trade-off is far from simple since the degree of uncertainty, which is a key parameter in the comparison, is not exogenous, as in the rules-versus-discretion literature, but depends on R&D firms' investment decisions, which are themselves determined by the legal institution.

[31] "An initial agency interpretation is not instantly carved in stone. [...] On the contrary, the agency must consider varying interpretations and the wisdom of its policy on a continuing basis, for example, in response to changed factual circumstances." (Chevron vs Natural Res. Def. Council, Inc., 467 U.S 837, 1984).

In the context of our model, we show that rigid legal systems are preferable (in terms of welfare and rate of output growth) in the early stages of technological development. Flexible legal systems are, instead, preferable at intermediate stages of development: output grows faster and welfare is greater. Finally, when technology is mature, the two legal systems are equivalent.

The amount of innovation in the rigid regime may be either inefficiently low or, under some conditions, inefficiently high.

The welfare comparison summarized above holds even when we assume that in the rigid legal system the statute (or regulation) can be changed ex-post at a cost.

In our view, the analysis above sheds light on how technological innovation is shaped by a system of Common Law, as opposed to a Civil Law one.

A natural question would be how our conclusions would change in an economy where R&D investment increases the *variety* of available goods (for instance as in Romer, 1990). Various results obtained in the current setting would likely survive. However, we expect the legislator in a rigid regime (where the law is not contingent on each variety) to discourage innovation, but not to induce overinvestment. Indeed, contrary to our conclusions, horizontal innovations always increase the complexity of the economy since new varieties coexist with old varieties. Therefore, the legislator in the rigid regime would likely have a bias against such innovations. Everything else being equal, we expect the rigid regime to grow at a slower pace than in the setting we have analyzed here.

Luca Anderlini (Georgetown University)
Leonardo Felli (London School of Economics)
Giovanni Immordino (Università di Salerno)
Alessandro Riboni (École Polytechnique and Université de Montréal)

Appendix

Proof of Proposition 2

There are three cases to consider.

i) When technology is at an early stage of development, using (15) we obtain that the ex-post optimal law is $\underline{a}$ in both states so that the flexible regime provides weak incentives to innovate. Since the rigid regime can replicate the flexible one by choosing $a_{\mathcal{C}} = \underline{a}$ and since the rigid regime can also choose $a_{\mathcal{C}} = \overline{a}$, it must be that $W_{\mathcal{C}} \geqslant W_{\mathcal{F}}$ and $E(g_{\mathcal{C}}) \geqslant E(g_{\mathcal{F}})$.

ii) Suppose now that technology is at an intermediate stage of development. In the flexible regime, from (15) we conclude that the law enforced in state 1 (resp. 0) is $\overline{a}$ (resp. $\underline{a}$). In the rigid regime, as shown in (25), two cases are possible: $a_{\mathcal{C}}$ is either $\underline{a}$ or $\overline{a}$. First, assume that $a_{\mathcal{C}} = \underline{a}$. Given (11), this implies that the probability that state 1 occurs in the rigid regime is lower than in the flexible one. Using (27) and (28) we have that $E(g_{\mathcal{F}}) > E(g_{\mathcal{C}})$. Moreover, when $a_{\mathcal{C}} = \underline{a}$ it is possible to show that $W_{\mathcal{F}} > W_{\mathcal{C}}$. This is because $\underline{a}$ does not maximize the indirect utility in state 1 and because state 1 (which by Assumption 1 provides greater utility than state 0) is more likely in the flexible regime. Second, assume that $a_{\mathcal{C}} = \overline{a}$. Plugging the ex-post optimal laws and $a_{\mathcal{C}} = \overline{a}$ into (28) and (27), we obtain that $E(g_{\mathcal{F}}) > E(g_{\mathcal{C}})$. To show that $W_{\mathcal{F}} > W_{\mathcal{C}}$ first notice that when $a_{\mathcal{C}} = \overline{a}$, the probability that state 1 occurs in the two regimes is the same. Moreover, recall that in (11) we assumed an interior solution for R&D investment. Then, the probability that state 0 occurs is strictly positive. Since $\overline{a}$ does not maximize $u(a, 0)$, we conclude that also when $a_{\mathcal{C}} = \overline{a}$ we have $W_{\mathcal{F}} > W_{\mathcal{C}}$.

iii) Using Definition 1, when technology is mature we have that $\vartheta(0) \geqslant 0$ and $\vartheta(1) > 0$. In the flexible regime, we know from (15) that law-makers select $\overline{a}$ in both states. In the rigid regime, from (25) we conclude that $a_{\mathcal{C}} = \overline{a}$. This implies that welfare in the two regimes is the same and, using (27) and (28), that $E(g_{\mathcal{C}}) = E(g_{\mathcal{F}})$. ■

Proof of Proposition 3

To be able to show, using (11), that R&D investment in the flexible regime cannot be larger than the one under the first-best law, we must show that $a_1^{ep} \leqslant a_1^{fb}$. Two cases are possible: $\vartheta(1) \geqslant 0$ and $\vartheta(1) < 0$. First, when $\vartheta(1) \geqslant 0$ in the flexible regime as well as under the first-best law we have – using (30), (31) and (15) – that the law for the more advanced technology is equal to $\overline{a}$, so that investment in the flexible regime is identical to the first-best level. When $\vartheta(1) < 0$, from (15) we obtain that law-makers in the flexible regime choose $\underline{a}$. Therefore, the amount of R&D investment under the first-best is necessarily (weakly) greater than in the flexible regime.

In order to prove that the commitment regime may induce overinvestment in research, we must show that there exists a region of parameter values where $a_{\mathcal{C}} = \overline{a}$ and $a_1^{fb} < \overline{a}$. First, assume that parameters are such that $\vartheta(1) < 0$. (When $\vartheta(1) \geqslant 0$ innovation in the first-best is already at the maximum level and the commitment regime can at most grow at the same rate). Consider the following parameter values: take $\overline{a} = 1$ and $\theta^2\phi(1) = 1$ so that if the law is $\overline{a}$, state 1 occurs with probability one. In this case, we have

$$W_{\mathcal{C}} = \max_{a \in [\underline{a}, \overline{a}]} (1-a)\vartheta(0)\, a + a\vartheta(1)\, a. \tag{35}$$

Using (25), one can show that the law in the rigid regime is 1 if

$$\underline{a} > \frac{\vartheta(1)}{\vartheta(0) - \vartheta(1)}. \tag{36}$$

Using (30) and (31) we know that when $\vartheta(1) < 0$ we have that $a^{fb}(1) < 1$ if and only if

$$\underline{a} < \frac{2\vartheta(1)}{\vartheta(0)}. \tag{37}$$

One can verify that when $\vartheta(0) < 2\vartheta(1)$ it is possible to find a value for $\underline{a}$, with $0 < \underline{a} < 1$, such that both (36) and (37) are satisfied, which proves our claim that at least for some parameter values the rigid regime induces overinvestment. Notice that since (36) and (37) are strict inequalities, our claim remains true when $\theta^2\phi(1)$ is sufficiently close to one so that, as we assumed in the paper, the probability of state 1 is strictly lower than one. ■

Proof of Proposition 4

There are three cases to consider.

i) When technology is at an early stage of development, the ex-post optimal law is always $\underline{a}$ so that the flexible regime does not provide any incentive to innovate. The partially rigid regime, on the contrary, can choose to provide incentives. Therefore, exactly as in case i) of Proposition 2, the rigid regime could replicate the flexible one by picking $\underline{a}$, so that it must be the case that $W_{\mathcal{C}} \geqslant W_{\mathcal{F}}$.

ii) Suppose now that technology is at an intermediate stage of development. We first show that for all $\kappa > 0$ we have $W(\kappa) < W_{\mathcal{F}}$. To see this, notice, from (30) and (31), that the laws in the flexible regime coincide with the first-best law. Then, it is immediate that $W(\kappa) \leq W_{\mathcal{F}}$. To show that $W(\kappa) < W_{\mathcal{F}}$, notice that in the partially rigid regime two cases are possible: $a_{\mathcal{PC}}$ is either changed or not changed ex-post. First, assume that $a_{\mathcal{PC}}$ is not changed. In this case, in the partially rigid regime a single law is enforced under both states. Since the probability of innovation is assumed to be strictly below one and since at this stage the ex-post optimal laws are different in the two states, with strictly positive probability the partially rigid regime enforces a law that is not ex-post optimal. Then, $W(\kappa) < W_{\mathcal{F}}$. Second, assume that $a_{\mathcal{PC}}$ is changed ex-post. Since the cost k is incurred, we obviously have $W(\kappa) < W_{\mathcal{F}}$.

To show that $W_{\mathcal{C}} \leq W(\kappa)$, recall, from (25), that in the rigid regime the law is either $\underline{a}$ or $\overline{a}$. First, suppose that the rigid regimes chooses $\underline{a}$. To show that $W_{\mathcal{C}} \leq W(\kappa)$, notice that if $a_{\mathcal{PC}} = \underline{a}$, welfare in the partially rigid regime would be weakly greater than in the fully rigid regime. To see this, first notice that if innovation does not occur, welfare in the two regimes would be identical. However, if the new technology is discovered the legislator in the partially rigid regime has the possibility of changing the law to $\overline{a}$ after paying a cost. It follows that in the partially rigid regime the probability of innovation and welfare in state 1 are weakly greater than in the rigid one. We can, therefore, argue that $W_{\mathcal{C}} \leq W(\kappa)$. Second, assume that the rigid regime chooses $\overline{a}$. Notice that in the partially rigid regime we could achieve a higher welfare by choosing $\overline{a}$ as $a_{\mathcal{PC}}$. Indeed, the probability of innovation as well as the indirect utility in state 1 would be the same under the two regimes. However, if R&D investment does not succeed (an event occurring with strictly positive probability), welfare in state 0 would be weakly greater under the partially rigid regime since the legislator has the option to change the law ex-post and choose $\underline{a}$. As a result, we have that $W_{\mathcal{C}} \leq W(\kappa)$.

iii) When the technology is mature, $A(0) \geqslant 2$, using Definition 1, it is immediate to verify that the law $a_{\mathcal{PC}}$ in the partially rigid regime is equal to $\overline{a}$ for all κ. Moreover, for $i = 0, 1$ we have that $a_{\mathcal{PC}}$ is ex-post optimal. Welfare in the rigid regime does not depend on κ since the law is never changed ex-post. Then we have that $W(\kappa) = W_{\mathcal{C}} = W_{\mathcal{F}}$ for all κ. ■

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