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Toward a theory of Smart Institutions

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Abstract
We present an analytical approach to institutional analysis that draws inspiration from control process engineering in the physical sciences. We characterize smart institutions as having three foundational features. First, smart institutions are context sensitive and expressly allow for a unified consideration of social, political and economic factors, thereby providing a richer and more eclectic approach to their operation. Second, smart institutions are forward-looking in their operation rather than deriving from their past functions and purpose in contrast to most generic institutions. Third, as opposed to generic institutions, smart institutions emphasize the role of information and specifically that of subjective social feedback on institutional performance. A theory of smart institutions, consequently, presents distinct advantages over traditional institutional analysis.

Keywords: Institutional analysis, Institutional development, Control process engineering, Information entropy, Fuzzy feedback

JEL Classification: D02, E02, O43, P0

1 Background

The rapid flow of information across societies has now become the norm, and a consequence of this is evident in the remarkable transformation across a variety of institutional forms. Consider two interesting and relatively recent cases: open science and free culture. The former enables mass participation in scientific endeavors, and the latter advocates the free distribution of all forms of creative content over the internet.[1] Neither is the change in institutional forms limited only to narrow scientific or cultural endeavors. Even in the broad context of economic reform, Rodrik (2008) suggests the idea of 'second-best' institutions, proffering two notable arguments. First, that a variety of institutional forms, observed in different contexts, achieve similar objectives, and that this puts into question any presumption of a unique set of institutional blueprints. Second, that the objectives of an institution vary by the context of their environment. For example, in the early stages of development, the encouragement of entrepreneurial activity relies on a more strident protection of rent, and the timing of import liberalization after export liberalization eases the burden of trade liberalization policies generally. However,

[1] While examples abound, merely as glowing exemplars for each category one might consider Galaxy Zoo for open science, and Creative Commons for free culture.

while institutional change is neither new nor novel, our contention is that the information era brings with it an existential challenge to traditional institutional forms.

The motivation for this paper is our belief, shared by many researchers in the field, that there is more merit in an approach that examines the effectiveness of institutions by acknowledging how, in practice, they are characterized by complex structures and social interdependencies rather than assuming such complexities away. We argue that broadly three categories of institutions must be distinguished: economic, political and social. However, we aver that they must then be looked at simultaneously as three related dynamical systems to underscore their interdependencies. Doing so concentrates focus on the processes of institutions rather than on their traditional labels. Since we wish to suggest a methodical manner of achieving this, we propose a theory of *smart institutions*; we adapt the framework of control process engineering that is well suited to deal with complex and integrated dynamical systems in developing this approach.

Smart institutions differ from traditional or generic institutions in three essential and distinct aspects: their *context sensitivity*, their *forward-looking* perspective and the foundational role of information and *feedback* in their operation. The aspect of contextual sensitivity in smart institutions derives from a unified consideration of social, political and economic factors. While specific smart institutions may favor such factors to varying degrees, their setup is expressly based upon an eclectic consideration of effects across the societies they operate within. Smart institutions are also progressive in their operation; this is a key distinction since it makes them less susceptible to the institutional inertia that routinely characterizes (and plagues) generic institutions. Finally, smart institutions emphasize information flows and the consideration of the value of subjective social feedback in order to inform their operations.

In our view, the crucial role of information and feedback in the analysis of institutions cannot be overstressed, especially if our ambition is to have smart institutions as the basis for a modern society.[2] Smart institutions are based on the systematic incorporation of information in their operation; indeed, this is an integral part of the setup we propose. Contrast open science or online education initiatives to the traditional institutions that have historically curated those practices; one of the key points of difference in our view is that smart institutions are much better at dealing with larger and more varied sources of information.

Our theory for smart institutions spans the social sciences and emphasizes a dynamic and circular flow of information; in a system of smart institutions, the steering institutions interact with their environment to effect economic, social and political change; the impact of such changes creates feedback that recursively affects the behavior and the overall design of the system. This emphasizes the central role of information and social feedback in our theory.

We inform our theory on smart institutions with the methodology of modern control process engineering expressly because of its ability to handle complexity and to adapt to varying contexts. In Sect. 2, we outline the logic of how a control engineering process operates and examine how this translates to a social process. Given the novelty of this

[2] We owe the conviction of our thinking on this issue to the idea of the 'adaptive efficiency' of the institutional matrix in a society as presented in North (2010).

approach, we develop much of the intuition using simple economic, social and political examples, which serve as our counterpart to a simple control engineering process like a thermostat used to regulate temperature in a room. However, it is worth emphasizing at the outset that the same control engineering paradigm that governs the workings of a thermostat can be used to handle a far more complex system like an airplane. Likewise, our theory for smart institutions presented in this paper is capable of analyzing models based on complex or general social, economic and political interactions as well as more specific or simpler versions. In Sect. 3, we investigate each element of our approach introduced in Sect. 2 in greater depth while underscoring, in the process, linkages to well established theories in the social sciences. This section also examines the nature of social feedback and the role of information in smart institutions. In Sect. 4, we incorporate PID tuning (a basic control process engineering methodology) to examine how smart institutions impact social processes based on social feedback. We offer some concluding comments in Sect. 5.

2 A control-theoretic framework for building smart institutions

In this section, we lay the groundwork for what we mean by smart institutions using the perspective of control theory, where the emphasis remains squarely on the dynamic functioning of an entire system based upon the role of contextually relevant information in guiding institutional control. Naturally, a certain degree of latitude is needed in applying this setup to the social scientific study of institutions, where overriding and precise laws (such as those we find in physics) are absent.[3] With that caveat, we begin by introducing the terminology for such an evaluation.

Smart institutions can be considered to operate in a *closed control loop*, as depicted in Fig. 1. While elaborating on each component, we will find it useful to draw the parallels between institutional analysis and control process theory in engineering applications as depicted in Fig. 2.

Much like a heating system, comprised of a furnace and a thermostat, that exists to influence the temperature of its surroundings, we can think of a society as a system that seeks to influence an *output*, y. When we are concerned about how this system operates dynamically, we can equally consider an output, y_t, that is produced at some time t. Depending on the context (i.e., social, political or economic), y may be interpreted differently. Broadly, it may be understood to measure the modernization of a country, which is clearly a multidimensional growth process. It may instead, depending on the context, be also interpreted as the economic development of a society. If the focus of attention is a single institution like a regulatory body governing environmental issues, we may wish to interpret the output as the air quality index. No matter what the context, however, the output is something the level of which can be controlled, at least to some degree, by the system.

The operation of a system (whether an engineering system or a society) and its ability to produce a desired output relies on the interaction of a *controller* and a *plant*, which comprises an *actuator* and a *mechanism*. In the context of smart institutions, the

[3] While the use of Control Process Engineering in the social sciences is extremely rare, see Goorha (2009) for an application linking the political and economic development dynamics.

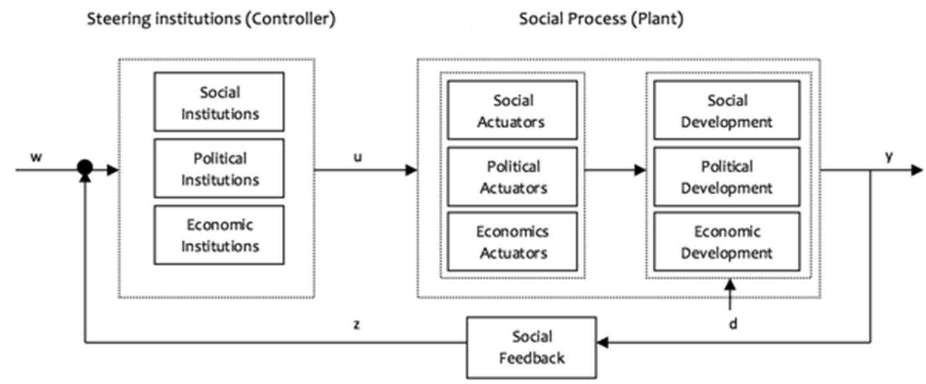

Fig. 1 Components of a smart institutions system

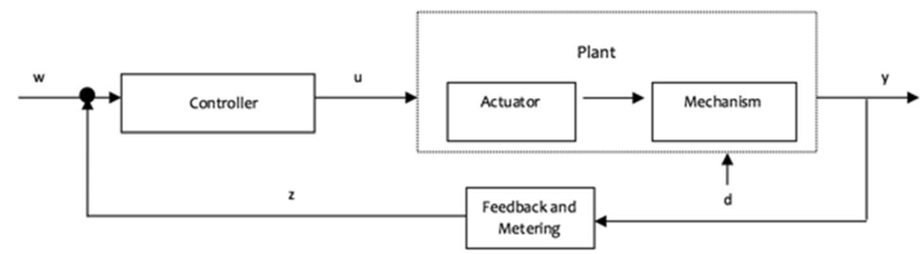

Fig. 2 Control process in engineering

controller is a complex or set of economic, social and political institutions, which we call the *steering institutions*. The steering institutions seek to control the behavior of the *social process*, or plant, which produces the output. The steering institutions generate a set of *reference variables* (w_t) that can be interpreted broadly as the objectives over a set of variables that the social, economic and political steering institutions interactively and collectively define for society. In congruence with control theory, we envisage the management of smart institutions to involve *feedback*, and we imagine this feedback to be drawn from members of the society that the steering institutions represent.

In order to influence the behavior of the social process (plant), the steering institutions (controller) produce 'low-powered' *actuating signals* (u_t) based on the specific mechanisms of control that the institutions oversee, and their levels depend on the behavior of the output in contrast with the reference variables; in other words, the actuating signals are, in some sense, a function of the reference variables. While the precision with which actuating signals are produced in practice may vary, it is this tractable and direct dependence of actuating signals upon reference variables and feedback that is at the foundation of what makes smart institutions 'smart.'

In control engineering systems, actuators transform the low-powered actuating signal into a higher-powered signal sent to the mechanism that is able to produce the output. For smart institutions, based on the actuating signals that are received from the steering bodies, the social, political and economic actuators, within the plant then generate *higher-powered signals* (s_t) sent to their respective development mechanisms that, along with random disturbances (d_t) affecting the system, determine y_t. Thus, a political institution may actuate the sternness of its regulatory body which then uses its higher power of intervention in the market to modulate an outcome or a social religious institution may actuate the religiosity of its many adherents to enable a mobilization effort in effecting an outcome. Therefore, it is the efficacy of the allied actuators in transforming low-powered institutional signals into a high-powered effort that imparts significance to any given institution within the wider complex of institutions.

In an engineering process, a low-powered signal is one that consumes little energy in its production and transmission. The social science counterpart of this is the generation of a low-cost or low-effort signal. The actuating signals are low powered in this sense; examples would include an interest rate announcement by a central bank, a manifesto issued by a political party to which its members must adhere, an opinion expressed by the head of a religious organization, and so on. In all these instances, the signals have low costs to generate and, implicitly, low cost to implement as well. The central bank implements its interest rate policy through open market operations, the political party may enforce its manifesto on its members through the threat of expulsion, and the religious head may rely on the consequences implied by a religious text to ensure compliance. In contrast, the signals sent by actuators to the mechanism are high powered in the sense that they involve a high cost or effort for their generation and implementation. A bank, for example, must assess the impact of the change in interest rates imposed by the central bank and re-optimize its own strategy to maximize its profits, which will involve changes to its borrowing and lending activities that then permeate through the economy. Similarly, the manifesto of a political party must be communicated to voters by members of the party through effort in the form of political meetings, media appearances, distribution of flyers, door-to-door canvassing, etc. The views of the head of a religion must be absorbed and communicated by religious figures such as priests through sermons. In all these cases—banks, political party members, priests—the efforts for generating and implementing their signals are relatively high compared to actuating signals.

Indeed, the low-powered actuating signals are incapable of generating an output on their own and rely on the galvanizing force of high-powered signals produced by actuators to achieve this. This allows us to concretize the meaning of effectiveness of a social, economic or political institution and to distinguish between weak and strong institutions. We investigate this further in Sect. 3.3. The impact of the output on the reference variables is then assessed by members of the society, and once this information is processed, it is transmitted to the steering institutions and considered by them. Thus, there exists the idea of feedback, or *metering*, which is an evaluation process that produces a set of *feedback variables* (z_t). It is worth noting that this characterization of z_t as an evaluation is broad enough to incorporate not only hard data and statistics, but also social commentary and opinion. We imagine feedback in its most general form and allow it to encompass any information that can influence the design of the reference variables. Depending on how the subjective performance of the system, as expressed by z_t, compares with the reference variables (w_t), the steering institutions design the reference variables for the next period (w_{t+1}), and the process repeats itself.

The feedback process in the social science context is far more complex than feedback in an engineering system, and this carries implications for the operation of a system of smart institutions. Nevertheless, it is in the degree of tractability and open verifiability of this process that we see the key distinction between what constitutes a smart institution as opposed to any generic institution.

While we elaborate on this further in Sect. 3.5 below, at this stage consider a simple example that captures the elements involved: an environment protection agency as a smart institution. The agency might raise the price of carbon credits to control pollution. In any economy, especially in the presence of internal and external shocks, the impact of this policy on unemployment may be less than certain. In particular, if unemployment does rise appreciably, the consequences of an economic downturn may move into the social sphere through, say, higher crime rates. If the downturn persists, the government may be held responsible, and the impact is felt politically as well. As opposed to a generic institution, where such feedback from society is ordinarily a second-order consideration, for a smart institution the relevant steering bodies would directly consider their feedback sources, be they academics, the media and the average voter. A number of issues arise here, and while they may not be novel, the manner in which the feedback informs the operation of the institutions is crucial to a theory of smart institutions. First, the feedback process may generate useful new information, or it may generate information that is already expected by the steering institutions. In Sect. 3.5, we discuss the concept of entropy that enables us to measure the *value* of feedback for the steering institutions, but a key point of difference between generic and smart institutions is worth noting here. While a generic institution may also solicit and consider feedback, its relevance to the functions of the institution is not critical. For smart institutions, on the other hand, the value of the information to the process of their operation is paramount.

Second, it may be impossible to segregate feedback as being entirely relevant for a single steering institution. For example, voters who remove an incumbent government from power may be unhappy not only with the government's handling of unemployment, but also with rising crime in society. Feedback may, therefore, be fuzzy in the sense that it may be relevant for economic, social or political institutions to varying degrees. As opposed to generic institutions, smart institutions would not discard as irrelevant information that does not directly inhere to the scope of their remit.

Third, smart institutions are capable of incorporating fuzzy or qualitative feedback and quantifying it for their steering institutions. In Sect. 3.5, we discuss the implications of fuzzy feedback.

Embedded in the theory of smart institutions based upon a control process is the idea that their relevant steering institutions function as *automatic controllers* do in control process theory, where the term automatic refers to the fact that they initiate action based on discrepancies perceived between the desired outcome and the actual outcome of the system. More specifically, their role is not only to provide the reference variables, but also to then use their individual steering mechanisms, which are different for different institutions, to devise the values for their actuating signals given knowledge on the behavior of the plant, the levels of the disturbances over time and, crucially, the control error between the reference variables and the actual outcome. This is the idea of 'automatic control,' and with advances in modern control theory, where controllers may be built using fuzzy logic, the parallels with the less precise field of institutional analysis are starker and more useful still.

We can now see how the various elements in our model for smart institutions integrate for a single iteration of the entire system. Consider the simple example of a presidential system, like the USA maintains, as a smart institution with the office of the president serves as a steering institution. Suppose the set of reference variables comprise a vector of elements, where each element pertains to a specific department of the government, with the cabinet secretaries functioning as actuators. To implement these objectives, the president's office generates actuating signals, or directives, that are sent to each cabinet secretary. The actuators (secretaries) take these low-powered signals and generate high-powered ones that are capable of influencing the output. The bureaucracy within each department functions as the main mechanism of the plant where this high-powered signal is converted into an output. For instance, the Department of Education may be sent a directive based on an executive reference variable on average examination scores to be achieved by public schools; the Department for the Environment may be sent a directive based on a reference variable for a certain amount of reduction in carbon emissions; the Treasury may be sent a directive based on a reference variable for the fiscal deficit and so on. Indeed, each department may be sent a multiple of directives based on a single or more than one reference variables.

A similar transformation is achieved by the vector of high-powered signals between the matrices of directives and functions within the plant that correspond to influencing them. The bureaucracy within the Department of Education, for example, may have to decide how to allocate scarce public funds among the various public schools, determine the incentives provided to teachers and set minimum standards for the adoption of new technology into classrooms—all this with the goal of achieving the directive(s) given to their department, depending on the reference targets set by the executive. As the agents in the plant, the bureaucracy in our example, respond to these high-powered signals, the output over the course of time will be realized. At a very elementary level, the output may have achieved the targets set out in the reference variables. Or, due to a number of factors the output may be far away from the targets intended by the steering institution. These factors could include the degree of bounded rationality of the steering institution in setting the references, the inability of translating reference variables into clear or acceptable directives, the capabilities of the bureaucracy, the inherent uncertainty in the environment and so on

Once the output is produced, its impact is assessed by members of the society. For instance, it may transpire that the fiscal deficit incurred by the treasury is deemed too inflationary. Or it may eventuate that the move toward a reduction in carbon emissions is considered to be too aggressive by a majority of the society, and held responsible for a recessionary pressure on the economy. Or the emphasis toward average school leaving scores is viewed as stifling creativity among children. Or, even if the original reference variables are viewed favorably, the bureaucracy may have been inefficient and fail to implement schemes that are successful. All these effects will be gauged by members of the society, and the information transmitted to, and absorbed by, the steering institutions. This feedback, along with the actual realization of the output, may influence the reference variables selected by the steering institutions in the next period; for example, the targets on carbon reduction and fiscal deficit may be revised, and less emphasis placed on school leaving scores. The manner in which the steering institutions respond to social feedback is, of course, context based; for example, we can imagine that a government formed through a dictatorship is (typically) less responsive to social feedback than one formed through a democratic process.

This example, while simplified for the sake of illustration, highlights the dynamics of how a system of smart institutions might operate, and the crucial importance of their steering institutions in setting the reference variables and in determining how these reference variables respond to social feedback. As the process unfolds, steering institutions may learn not only how to modify the reference variables, but also the efficacy of the signal generation process. Institutional analysis becomes specifically important in this control-theoretic conceptualization of smart institutions for the precise purpose that it answers the question of how information is processed to generate values for a large set of actuating signals that, in turn, help make the output of the overall system respond to the reference variables. This focus provided to the analysis of real-world institutions is especially useful for the tractability it imparts.

3 A discussion of the components of smart institutions

The use of control theory provides a useful general approach for studying the overall functioning of smart institutions, for it is amenable to being developed in as elaborate or complex a manner as is desired, just as it is possible to use it to simplify institutional analysis. For instance, in engineering applications, an engineered plant can be as simple as a thermostat or as complicated as the autopilot system onboard an advanced fighter jet. Similarly, depending on the context under analysis, we could consider an array of steering institutions, multidimensional signals, complex forms of output and sophisticated methods of feedback in the construction of a model of smart institutions. On the other hand, using the same control-theoretic structure described in Sect. 2, we could focus on a single steering body within a smart institution and a scalar output with simple mechanisms for generating signals and feedback.

Section 2 identifies the main elements of smart institutions: *steering institutions* that generate low-powered signals, *actuators* that transform these to high-powered ones, *output* that is produced by the actions of the steering institutions and actuators within a social process, and a social *feedback mechanism* that influences the steering institutions' choice over reference variables. In this section, we explore each of these elements in depth.

3.1 The steering institutions

The seminal contributions of Williamson, North and Ostrom have served to mitigate opposition in the mainstream economics literature to the idea that institutions matter to economic development and that, more generally, they are a significant component in our understanding of how societies develop. Even when examined alongside other factors in comparative analyses institutions seem to have a predominant effect. Rodrik et al. (2004), for instance, emphasize the primacy of institutions among the factors that influence the relative affluence of societies.

Given that institutions do seem to matter to the development of societies in general, and an economy in particular, it is surprising that institutional analysis in economics often manages to underplay their relevance. We propose two reasons for this negligence, both of which are made explicit in our theory on smart institutions. The first is the question on whether there is some order, chronological or hierarchical, in which different types of institutions exert their influence. The second is our contention that, in examining particular outcomes, where institutional analyses focus on the institutions themselves, they will be likely to miss the indirect effects of the control they exert.

While there has been some debate surrounding this issue, the general assessment seems to be that the order in which institutions manifest their influence can affect the path that development takes. For instance, Acemoglu et al. (2005) suggest that the success of European economic performances on the back of Atlantic trade can be explained by a sequence of changes, where political institutions took a leading role in responding to the incipient prospects of beneficial trade by developing better mechanisms for the establishment and protection of property rights, which facilitated the subsequent innovation and developments in economic institutions. Williamson (2000) goes a step further in suggesting four levels for the order of change among all forms of institutions in operation in a society. The first level corresponds to what we perceive as social institutions in our set up—institutions that are predominantly characterized by informal rules, norms and religion. The order of change here is very slow, and Williamson suggests that change is minimally over a century. The second level corresponds to the characteristics held by political institutions in our model or institutions that determine and enforce the formal rules of the game such as the judiciary and the polity. Here the order of change is typically as little as a decade to as much as a century. The third level comprises what we have in mind as economic institutions, and typically contains those institutions that actually assist in 'playing of the game' and contracting. The order of change here is as little as a year to as much as a decade. The final level is that of interaction within the market, where change is continuous.

Our view is that a focus on the order in which institutions exert their influence or any hierarchy that exists among them, while interesting in some contexts, does not provide a useful general understanding of how institutions and societies interact. This is why the circular flow of signals and information that forms the core of our model for smart institutions suggests a more dynamic and flexible superstructure, within which each element is inextricably linked to others. In this, our view is perhaps closer to sociologists who emphasize the relevance of institutions to all aspects of social interaction (see, e.g., Portes 2006). Sociology also deals with institutions based on informal rules and norms, constructs that economics and positive political science are comparatively ill-equipped to deal with—issues such as the role of identity, traditions and culture, trust, religion and social classes. This is not an insignificant omission. Some economists concede that the relative role of informal institutions in comparison with their formal counterparts cannot be disparaged. Williamson (2009) recently argues that informal institutions in fact strongly impact development and that, further, the success of formal institutions rests on codified informal constraints. Similarly, Aghion et al. (2010) suggest how countries with higher levels of trust require lower levels of regulation, arguing, therefore, that a link exists between formal institutional development and the level of trust. There is a need, therefore, for a broader interpretation of the role of institutions that extends beyond a piecemeal study of economic, social and political institutions; their interaction, in fact, is crucial to understanding the influence they have.

In accordance with control theory, the steering institutions in our theory of smart institutions have an impact on outcomes that is partly deterministic, but, at the same time, also indirect. These features of determinacy and indirectness provide an understanding of the link between the signals generated by institutions and dynamic social processes, which is seldom the focus in the literature on institutional analysis. Consider, for example, how stated desires and suggestions, or even directives and commands, produced by a society's institutions get translated into processes that affect real-world outcomes. How precisely does an institution implement the various processes that control, or steer, social outcomes toward their desired levels? The signals sent from the controller to the actuator are low powered and incapable of controlling a large physical plant, such as a signal sent first to change the angle on a wing flap to change the actual flight path of a large airship. As such, there is the need for actuators that can convert the low-powered signal into one of higher power, such as by employing the use of driving motors on the wing in this example. Similarly, a steering institution may generate an actuating signal, such as a public announcement made by a church, a central bank or a political party, which must then be transformed by actuators such as believers, banks or activists into a signal of high enough power to have an impact on social processes. In other words, institutions trigger actuators, which then amplify the signals they receive to enable the outcomes produced by the plant. This need to convert low-powered signals to high-powered ones makes the effect of institutions, when examined directly, much more indirect and far less obvious than extant economic and political analyses would suggest.

There is basis in the literature for our view. For instance, Persson (2002) argues that there is a determinacy between the manner in which political institutions are established and the economic policies that they pursue. Glaeser et al. (2004) suggest that the effect that political institutions have on economic growth is muted if one considers the more dominant role that human capital plays in enabling growth directly. Indeed, Doucouliagos and Ulubasoglu (2008), in a sweeping meta-analytic study conducted over 81 papers in the field, suggest that the effect of the political institutions associated with democracy (construed broadly) on economic growth appears to be patently indirect.

3.2 The output

In control process engineering theory, the output of a system under consideration can be as variegated as temperature, speed, effort, and so on. Engineers, therefore, are able to use the same underlying principles in a wide array of applications. The versatility of this approach makes it ideally suited as the basis for a theory of smart institutions, where the vast array of social contexts exceeds even the applications found in engineering. Depending on the context, then, the social scientist may wish to consider a microcosm of economic activity and focus on the output produced in a single industry, or a take broader perspective and focus on growth of gross domestic product of an entire economy.

For our purpose of attempting to integrate the study of social, economic and political institutions, in this section, we characterize the output as development in its broadest sense: an index capturing weighted growth in social, economic and political variables defined each period by social, economic and political institutions. Taking such a broad view allows us to elaborate on how steering institutions influence a society's development and how they respond to social feedback. In other words, it permits us to take an integrated view of institutional influence on society. While this is without doubt a complex exercise, control theory provides the very tools we require to handle this complexity tractably.

Our starting point is the observation that development in a society, as defined above, cannot occur without the use of scarce resources. This economic principle of the scarcity of resources is the necessary condition that motivates choice, and holds equally true for most social and political variables as well. A social entity like a church is influenced in its decisions by the scarcity of resources it controls to the same extent as a profit maximizing firm even if its motivations and the nature of its output may be different. The local church may, for example, consider its output to be a vector comprising the promotion of religiosity, providing shelter and food to the homeless, and educating children. The extent to which this output grows over time (that is, the church develops) will always be constrained by the revenues it is able to collect, the assets it has in place, the availability of pastors, and so on. In the absence of regulation (e.g., laws over property rights and the enforcement of contracts) that controls the exploitation of scarce resources, the competitive drive to exploit these limited resources would result in their rapid depletion and, consequently, lead to a growth path that is unsustainable. This market failure is the *tragedy of the commons*, and given the broad definition of development under consideration, it is an inevitable logical consequence of the under-regulation of society's resources.

While the tragedy of commons sends a strong signal for the need for regulation, in general, there is no guarantee that regulation achieves greater success than its absence.[4] First, there exists the possibility of excessive regulation that leads to under-use of resources, which hampers development. This possibility, which is referred to as the *tragedy of the anticommons*, provides a strong incentive to limit the scope of regulation. Second, there also exists the possibility of inefficient, or poorly implemented, regulation that fails to solve the market failure, or worse, even exacerbate it. Both these possibilities serve to highlight the strong prospect of regulatory failure as an impediment to development.[5]

To reiterate, the solution to the tragedy of the commons can result in the tragedy of the anticommons, and vice versa. There exists an elusive balance between the two, which reflects the balance between market failure and regulatory failure. The nature of interaction between institutions, groups in society that provide feedback and those that participate in the development process ultimately determines which tragedy manifests and to what extent. From the perspective of smart institutions, we can readily see that the steering institutions play a pivotal role in mitigating or in exacerbating a particular tragedy through the reference variables they begin with and the actuating signals they generate and that these signals respond dynamically to the development process. Institutions, in this view, not only determine the performance of the system in the short run (which seems to be much of what traditional economic theory focuses on), but also respond in the long run to feedback.

[4] Indeed, this is an essential insight contained in Coase's seminal paper on social cost (Coase 1960).

[5] To see the interplay of this market and regulatory failure, consider the example provided by Mohan and Goorha (2008) in the context of the oil industry.

Acemoglu and Johnson (2005) suggest that of the two broad types of institutions, as put forward by North—those protecting property rights and those that enable contracts by lowering transactions costs—it is the former that are more important for long-term growth since individuals adjust behavior to mitigate the problems posed by poor contracting institutions. But, in our view, this is neither a necessary nor a useful distinction based as it is on the assumption that instrumental action by rational and forward-looking agents mitigates the role of institutions, rather than explaining what role the institutions play in that process. This should become clearer in our discussion on actuators and social feedback in the following sections.

3.3 The role of actuators and social feedback groups

The key difference between the actuator and the social feedback groups is in their role within the overall system of smart institutions. Social, political and economic actuators operate within the plant and are verifiably allied to their respective institutions within the controller with the specific purpose of influencing the output. Social feedback groups, on the contrary, operate independently from the processes of the plant. The intricate manner in which actuators and social feedback groups operate in a society and the often subtle difference between the two is, we believe, one of the key reasons that make a unified theory of smart institutions in society much more fluid and complex than an engineered control system.

Tsebelis (1995) suggests that institutional or individual veto players in political systems are those whose consent is necessary in order to effect a change in the status quo. In a spatial voting setup, this is helpful in understanding how the size of the winset of the status quo legislative policy is affected by the number of veto players. However, as outlined in Sect. 2, an institution merely sends a 'low-powered' actuating signal; it is then the actuator's ability, determined in conjunction with their development mechanism, to take 'high-powered' action based on this signal which grants the institution the power to stand as a veto player in the first place. This comes from the social actuators being verifiably, and perhaps even legally, allied to the institution. This gives us a useful definition of 'weak' versus 'strong' institutions. An effective institution is one that enables a transformation of desired social objectives into outcomes. Our theory of smart institutions makes this precise by drawing attention to the process that an institution need employ to effect a desired outcome. The effort—which, in the very least, can be understood as costs—that an institution would perforce expend in generating any outcome would depend on the capability of the social process it controls. This, in turn, would be determined by the ability of social actuators to comprehend and agree to the actions implied by the signals they receive from the institution and, thereafter, the efficacy of their development mechanisms in the production of the outcome.

Let Δe_i measure the additional effort or cost incurred by a steering institution and Δe_j measure the additional effort or cost incurred by an actuator. Similarly, let Δy measure a change in output. We can define a parameter $\theta = (\Delta e_j)/(\Delta e_i)$ that measures the additional effort incurred by actuators for a unit increase in signaling effort by the steering institutions and a parameter $\phi = \Delta y/(\Delta e_j)$ that measures the additional output resulting from a unit increase in effort by an actuator. Intuitively, θ describes the effectiveness of the steering institution (controller) in generating effort from the actuators, and

ϕ captures the effectiveness of the actuators in converting effort to output. The overall effectiveness of the process is, then, $\mu = \theta\phi = \Delta y/(\Delta e_i)$, which summarizes the change in end output of the process arising from a unit change in signaling effort by the steering institutions. For any given reference variable w (and assuming no exogenous disturbance, d), a higher μ corresponds to a greater ability of the steering institutions to alter output so that it aligns with the desired outcome of w, and therefore corresponds to a stronger institution.

In contrast to actuators, social feedback groups are not inextricably linked to the operations of the plant and the production of the output, which implies that they may not be relied upon to magnify a 'low-powered signal' generated by the steering institutions. They indirectly impact the manner in which the steering institutions set reference variables by a process of conveying subjective information to the steering institutions on the impact of development (output) on society.

Simple changes to a smart institutions model provide useful reference points to suit specific contexts. For example, if we were to weaken or sever the links to and from social feedback, we could examine a situation where there is little or no institutional development. This could give us explanations for persistently poor institutions, repressive and highly redistributive institutions, and so on. By constructing a variant of the model where the link between the controller and the plant is weak, we could analyze a situation where institutional and civil society complexity does not translate to satisfactory social development outcomes.

The model laid out in Grossman and Helpman (1994) is useful in considering the difference between actuators and social feedback groups more explicitly. Each of the steering institutions can, in line with that paper, be seen to have a support function that draws its support from the strength of its actuators (and their development mechanisms) as well as the social feedback groups. The difference is that actuators are allied to their respective institutions, thus providing an externality on them upon the resolution of the common-agency game that arises from the steering institutions sending a signal to the plant. This perspective vividly suggests how the genres of institutions within the steering mechanism of institutions may have a synergistic relationship with one another as well as a confrontational one. It is also a helpful separation method for the classification of groups within a society, providing a useful link that seems missing in extant theoretical constructs—chiefly that of how institutions and all forms of social groups effect and are affected by social development outcomes (of which the development of markets and economic growth is but one).

The relationship between actuators and their development mechanisms within the social process (plant) of the smart institutions view is predominantly based on the galvanizing motivation of a shared benefit. As such the theory of clubs can be seen as a legitimate basis to analyze their organization. The benefit of a good that a club provides imparts a joint benefit, which, rather generally, is a good with any degree of non-excludability or joint consumption characteristics, but the club good also features a concave marginal benefit curve by virtue of it becoming rivalrous upon reaching a congestion point. However, for a system of smart institutions, we can understand groups of actuators and development mechanisms forming as the steering institutions enable production of the club good that they derive utility from. Social institutions may provide religion as a club good, political institutions may provide public goods or even political power as joint-benefit goods, and economic institutions may provide access to markets or common-pool resources as the club good.[6]

3.4 Actuators

While the prospect of a benefit allies the social actuators to the institutional controllers, there is still need to model their behavior. Recall that in control theory the actuators magnify the signal they receive from the controller from low to high power when they transmit it to the mechanisms they affect. Likewise, in the smart institutions view, this is the role the social actuators must fulfill as well. Once they receive a signal from the steering institutions, social actuators must magnify them using the strength of their development mechanism (determined, in part, by their collective influence and organizing ability) in order to effect a change in the output in the direction desired by the steering institutions.

However, how is this signal magnified by the actuators? What gives the institutions the ability to conscript the actuators' resources to convert its 'low-powered' signal into a higher-powered effort? Precisely who can qualify as an actuator? Can an individual be an actuator or must it be a collective entity? The answer lies in viewing the relationship between the actuator and the controller being that of a special case of an 'incomplete contract' between agents, with the output providing a joint-benefit club good.

The political rules (such as those embodied in a constitution), social customs and traditions, and the theoretical underpinnings of neoclassical economics upon which the steering institutions are based form an incomplete contract between the steering institutions and the actuators. The contracts are incomplete in their inability to specify comprehensive state contingent provisions. This inability may arise from bounded rationality that results in unforeseen contingencies, or from excessive costs in negotiating detailed comprehensive contracts, or from costs associated with writing contracts that contain provisions that are comprehensible to, and verifiable by, a third party (like a court of law) that may have no knowledge of the environment within which the contracting parties operate (Grossman and Hart 1986).

Once an institution and an actuator enter a relationship, the contractual incompleteness may have little consequence if the two can break the relationship with ease when an unspecified contingency is encountered and negotiations fail. What ties the actuator and institutions together are relationship-specific investments: investments that are costly to make and have less value outside the relationship than they do inside (Klein et al. 1978; Grossman and Hart 1986; Williamson 1975). As an example, consider a steering institution like the executive, the social process comprising the cabinet of ministers as actuators and the bureaucracies of their respective ministries as the development mechanisms. Both the executive and the ministers must undertake a multitude of relationship-specific investments: the executive must understand the efficiency and caliber

[6] A fundamental advantage of characterizing such a good is that we can visualize the manner in which actuator and feedback groups function to the theoretical underpinnings of Olson's (1965) logic of collective action. While the problem of free riding would naturally plague such a group, Olson suggested it is mitigated in cases where the benefit is provided only to active participants. He also suggested famously that the groups form to prevent the exploitation of the majority. These are useful distinctions: the former being apropos for actuator-development mechanism groups and the latter coming in useful to describe the motivation of feedback groups.

of the portfolio of its cabinet members, while the ministries must understand and implement government policies. Similarly, the governing body of a political party may undertake investments in cultivating its candidates who, in turn, must undertake investments specific to the political party. It takes no stretch of imagination to realize that steering institutions and actuators in social, economic and political contexts make significant relationship-specific investments that cement their relationship.

To this static description, we must add the dynamic linkages that are integral to our theory of smart institutions. First, there occurs a process of social feedback that constantly influences the steering institutions in its design of reference variables and actuating signals. Second, in as much as the generation of the joint-benefit good (output) suffers from the tragedy of the commons or anticommons, institutions must perfect the balance between market and regulatory failure, which may require a reorganization of actuators and their development mechanisms within the plant.

3.5 Social feedback

3.5.1 Information entropy theory

Social feedback groups like the feedback mechanisms in control systems are knowledge processors. They receive and process information on the output given their understanding of the reference variables and transmit this information back to the steering institutions. This enables the steering institutions to adjust or reset the reference variables, if necessary, and design actuating signals that modify the path of output over time. However, in discussing feedback our primary goal is to underscore the quality of information in a system and, also, more generally, indicate what constitutes 'information.'

The generation of social feedback can be understood to occur in the form of discrete random-variable signals constituted over a particular observation space. This feedback information is sent back to the controller. We imagine that these signals, given that they are generated by variegated and complex social processes, have varying degrees of uncertainty in their latent true meaning which must be deciphered by the controller.

In order to understand how institutions may process the meaning of these signals, we appeal to the theory of information entropy, which measures precisely this idea of correlating the uncertainty surrounding an outcome to its inherent meaning. This concept is used frequently in computer science with respect to the treatment of stochastic events within an algorithmic framework.[7]

Entropy of a discrete random variable measures the unpredictability of an outcome and is defined by employing the idea of self-information, which, in turn, suggests how much information is actually revealed by an outcome. This is highly relevant to us in the social feedback mechanism because the strength of information revealed by a signal from the feedback is what inherently matters in a system of smart institutions. The information contained in a signal depends on the probability of the signal z_i being generated and is defined as:

$$S(z_i) = -\log_2 [P(z_i)]$$

[7] We refer the interested reader to Jaynes (1957).

This suggests that the information revealed from a signal that has a low probability of being generated is higher, which implies that a rare outcome has a high 'surprisal' value in the sense that it reveals more information than an expected outcome. The entropy, J, of the signal generating source is then defined as:

$$J(Z) = \sum_{i=1}^{n} p(z_i)S(z_i) = -\sum_{i=1}^{n} p(z_i)\log_2 p(z_i)$$

As an example, consider the one introduced in Sect. 2, of a government that tries to implement specific policies in its departments. To simplify matters, let us focus attention on a specific department, say the Department for the Environment and consider two reference variables: reducing carbon emissions by a particular amount and providing a certain percentage of energy requirements through renewable resources. While these objectives have their obvious environmental benefits, they also impose costs on society. The reduction of carbon emissions through a carbon tax, for example, may erode the profits of businesses (at least in the short term) and increase the prices of some goods for consumers. Similarly, the use of renewable resources may add to the rising costs of energy. Suppose, now, society expresses its subjective evaluation over the impact of the realized value of each reference variable (output) based on the statements—'Very Happy: no change required,' 'Happy: minor modifications need to be made,' 'Satisfied: significant changes need to be made' or 'Unhappy: this policy needs to be trashed.' This permits 16 possible outcomes for the evaluation of output by society. Suppose the signal sent through social feedback to the steering institution is very coarse and is limited to the set $z_t = \{G, B\}$, where 'G' represents 'good' as the signal and 'B' represents 'bad.' The signal 'G' is sent when the evaluation does not involve 'Unhappy' for either reference variable, while the signal 'B' is sent when at least one reference variable receives an evaluation of 'Unhappy.' In this instance, 9 out of 16 outcomes will be transmitted with a signal of 'G' and 7 out of 16 outcomes transmitted with a signal of 'B.' Assuming that these outcomes are equally likely ex ante,[8] before receiving the signal, the steering institution perceives probabilities $P(B) = \frac{7}{16}$ and $P(G) = \frac{9}{16}$. The information contained in signal of $z_t = B$ is then $\log_2 \frac{16}{7}$, which exceeds the information contained in a signal of G (which equals $\log_2 \frac{16}{9}$), or the surprisal value of an appraisal of the outcomes as bad is higher to the steering institutions. Ex ante, prior to social feedback occurring, the entropy of the feedback is:

$$J(Z) = P(B)\log_2 \frac{1}{P(B)} + P(G)\log_2 \frac{1}{P(G)}$$

Now consider a finer partition of the outcomes in the signaling process, where a signal of 'G' is generated when the evaluation does not involve 'Unhappy' for either reference variable, the signal 'B' is sent when exactly one reference variable receives an evaluation of 'Unhappy,' and a signal of 'E' ('Execrable') is sent when both reference variables receive an evaluation of 'Unhappy.' The probability of each signal being generated (under the

[8] Though this assumption is unrealistic, it does simplify the intuition at work. It is, however, by no means necessary.

same assumptions as before) is $P(B) = \frac{6}{16}$, $P(G) = \frac{9}{16}$ and $P(E) = \frac{1}{16}$. The information contained in $z_t = E$ is $\log_2 16 = 4$ and exceeds by far the information contained in the other signals. In this instance, the 'surprisal' value of $z_t = E$ is high and, as such, would be of comparatively significant value to the steering institutions.

Feedback in control systems happens as outcomes are systematically evaluated for their consonance with the reference variables before the controller is fed this information to assist with its optimization dynamic. A surprisal event in this context is likely to be metered by the social groups as one that is rare or unpredictable in contrast to the reference variable, as will become clearer when we discuss the idea of tuning below. The crux though is that such feedback would hold more intrinsic information for the steering institutions.

3.5.2 Fuzzy feedback

In the real world, the measurement of social outcomes against targets (reference variables)—that themselves are rarely precise—causes a degree of ambiguity that, at first glance, seems entirely alien to the world of control theory and engineered systems.

How can a society possibly provide meaningful metering and feedback of outcomes to the controller when the references are imprecise to begin with, the efficacy of the actuators may vary across the types of institutions and over time, the sources of disturbances in the system are variegated, and metering may be inconsistent and unreliable?

Thankfully this is a complication that control theory not only caters for but is getting increasingly adept at dealing with using the idea of fuzzy control. In fuzzy control, the process of automated control is deliberately based on using heuristic and experiential knowledge. Verbal feedback (whether gathered from larger samples using surveys and polls or gained from specific expert knowledge) can be translated into definitive and quantifiable values. What fuzzy control allows is to contextualize the system's design using feedback that may appear to be imprecise or vague if it were to be seen as purely free of context.

For example, the interpretation of feedback received from a person of something being 'very hot' in the context of working in an aluminum smelting plant versus sitting in an office is naturally very different. Fuzzy control arrives at a more precise and useful underlying value for a controller's input from such feedback by allowing the descriptions to fall into fuzzy sets that can handle increasing degrees of membership rather than simple dichotomous classifications.

With our setup to institutional analysis, though, fuzzy control is simplified by the fact that social feedback will usually belong to only one of the three sets of steering institutions. Suppose social feedback consists of set of elements $z \in Z$. Let S, P and E represent the set of social, political and economic feedback, respectively. A fuzzy set of social feedback Z has associated membership functions $\mu_j : Z \to [0, 1], \forall j \in \{S, P, E\}$ that assigns every element $z \in Z$ a degree of membership, $\mu_j(z)$, to social, economic and political interpretations of that feedback. Consider, for instance, our example of the reference variables initiated by Department for the Environment developed earlier (in Sect. 3.4). The idea of entropy emphasized the amount of information contained by a signal, say $z = G$. If $S(z) = \log_2 \frac{16}{9}$, for example, the information contained by that signal is .83 'bits'; in essence, with 16 possible outcomes in this example, the uncertainty is reduced from 4 to 3.17 bits. To continue with the same example, one could pose the question whether this signal $z = G$ suggests a 'good' evaluation of the political decision making process (that is, in this context, the political steering institution), the acceptable economic consequences of these policies (of more relevance to economic steering institutions), or a favorable social impact through the move toward a cleaner environment (that social steering institutions would benefit from learning), or indeed, some mix of the three. If the feedback were 'crisp,' then one would have to assign the signal membership to only one of the three sets S, P or E; a fuzzy feedback, however, allows membership of varying degrees to all three. This perspective disallows any clear separation of feedback into purely economic, social or political domains, which is as it should be when adopting an eclectic view to institutional analysis.

Moreover, and importantly, fuzzy control allows a quantifiable interpretation of qualitative feedback, such as $z = G$. In our context, this quantifiable interpretation relates to the ability of social feedback to reflect society's view on what the reference variables should be, which we denote $\hat{w}_t$, and, thereby, provides the steering institutions guidance on whether or how the input signal should be amended. In our example, social feedback of $z = G$ is likely to be interpreted by the steering institutions as $\hat{w}_t$ that is closer to w_t than a feedback of $z = B$. In the next section, we investigate further how an institution might respond to social feedback in its signal to the actuators.

The idea of second-best institutions in Rodrik (2008) noted above is useful for drawing attention to the value of context sensitivity. The idea of fuzzy control as the basis of smart institutions forms a useful link between the first-best ideal and the second-best reality. Ideal institutions are based on the known or crisp sets within the universe of discourse, whereas the second-best are based on their fuzzy set counterparts and tend to be heavily based on the particular context of a given society.

4 Tuning for *smart* control

We now turn to the question of the methodology for how we might examine the exertion of control by the steering institutions in a system of smart institutions. In order to understand how the steering institutions incorporate social feedback in controlling the system, we introduce a critical part of the control process engineering setup—that of the tuning. In that regard, we take inspiration from proportional–integral–derivative (PID) tuning. PID tuning clearly suggests how a complex process or behavior, involving movement to and from a theoretical ideal or setpoint, may be manipulated and controlled. The overall tuning methodology is comprised of three components; in our context, the PID methodology serves to characterize how the steering institutions produce their signal to the social actuators.

To understand the manner in which PID tuning is used in engineering systems, consider a simple example. Suppose a thermostat is used as a controller to maintain the temperature in a room at a desired level (the reference variable or setpoint). The actual temperature at some point in time (output or process variable) may vary from the desired level; the divergence between the setpoint and process variable gives rise to an error. Sensors that monitor this error provide feedback to the controller, which must then generate an output in the form of an actuating signal to the air-conditioning unit, or the plant, to change the temperature in a desired direction. Intuitively, a proportional adjustment focuses attention on generating a signal that is proportional only to the current error without reference to accuracy in steady state. An integral adjustment process, by comparison, is much more sophisticated in that it adds past errors to the adjustment process and is, therefore, likely to achieve steady-state accuracy since the controller will always output an actuating signal as long as any error remains. Relying on integral action alone is, however, not ideal in the face of a large sudden error, and the actuating signal response would only become sufficient once the error has been allowed enough time to integrate. Finally, the derivative component reflects the rate of change of the error over time and is thus sensitive not just to a given error but to incipient changes in errors. These components can be combined to form a variety of algorithms for designing the controller's action such as P, PI, PD or PID control.

4.1 PID tuning for smart institutions

In moving from physical processes to social, economic and political processes, the increase in complexity, especially in the nature and implications of feedback, is not insignificant. In most engineering applications, for example, the role of feedback is ancillary, even to the extent that the control algorithm of the system can be illustrated by dropping the metering element's role altogether. This is because the physical laws affecting the system are far better understood. In a theory of smart institutions, on the contrary, the role of feedback is intrinsic and has implications on both the approach of the controller (the control algorithm) as well as the outcomes it generates over time. In many instances, the steering institutions may be influenced by the feedback to change the reference variables themselves rather than simply adjust the control action that they take in achieving a given reference variable.

In a smart institutions setup, the steering institutions output a signal measured on some numeric scale from the lower bound representing no adjustment to the upper bound representing maximum adjustment. Its function is to motivate the actions of the social actuators within the social process. Adjusting the signal level determines the desired rate of adjustment. A higher level corresponds to a desired goal of faster adjustment. We imagine that the steering institutions use PID control in this manner, which provides a methodical approach to incorporating the idea of how societies with varying levels of information would go about manipulating the behavior of their desired outcomes and what factors may come to affect this.

In this section, we attempt to modify the PID tuning methodology for the context of a smart institutions theory. In doing so, we focus on a discrete time version of the tuning process which provides greater intuition than a continuous time description. A move from the discrete to its continuous counterpart is, however, relatively straightforward.

Suppose that at time t the reference variable set by the steering institutions is w_t, which, via the control process, yields an output of y_t. Social feedback generates a feedback signal, z_t, which is naturally a function of the control error, but as described in Sect. 3.5, the social feedback also indicates the reference variables desired by society, denoted $\hat{w}_t$. This is a departure from most control process engineering systems where metering does not involve feedback on the setpoint targets, and is what makes our theory of smart institutions a more complex and interesting application. Now consider the situation at the end of period t. The divergence between the reference variables set by the steering institutions and those desired by society is $\hat{w}_t - w_t$. In period $t+1$, the steering institutions must determine how much change to bring about to the reference variables from the previous period, w_t, based on feedback. The reference variables in period $t+1$ are, then:

$$w_{t+1} = w_t + \sigma\left(\hat{w}_t - w_t\right) + \gamma_t$$

Here, $\sigma \in [0, 1]$ measures the sensitivity of the steering institutions to the divergence between its reference targets and those suggested by social feedback. The term γ_t is a shock parameter that captures any external influence on the setting of the reference variables by steering institutions. A steering institution that is entirely insensitive to social feedback is captured by $\sigma = 0$, while $\sigma = 1$, corresponds to a situation where the steering institution's response is driven entirely by social feedback. One could consider a situation where the steering institutions are given a different set of reference variables by social feedback in the next period. In a situation where $\hat{w} \neq w_t$, the steering institutions may interpret this feedback in two ways. On the one hand, they may believe that society conceives of them as being incapable of reducing the control error sufficiently using the previously defined references. In such a case, a steering institution may well set σ to a low level and attempt to concentrate efforts on adjusting its signal to the plant. On the other hand, the steering institutions may receive the feedback on reference variable on face value and agree to them as the new set of reference variables. For example, a politician that has taken a hawkish policy measure may receive negative feedback from society, which may include, both, an assessment of how the hawkish policy has not created the expected output as well as a recommendation to adopt a new policy that is more dovish. The steering institution may either choose to ignore the feedback on policy adjustment altogether and pursue the hawkish policy till the expected outcome is achieved or it may, instead, abandon the hawkish policy altogether in favor of the dovish version as suggested by society. We can also imagine a dictatorship that is impervious to social feedback as being modeled with $\sigma = 0$, while a more democratic political regime as having σ lie somewhere in the interval [0, 1]. Similarly, a central bank that has a mandate to target inflation, say always to lie below 3 %, will retain this reference variable no matter what the social feedback is on the outcome or the reference, and like the dictator above, can be modeled with $\sigma = 0$. On the other hand, a government that attempts to implement a new policy to reduce carbon emissions by a certain percentage by introducing a carbon tax may be very sensitive to the social feedback on its policy; in this instance, we would expect σ to lie close to 1.

The expression for w_{t+1} as stated above captures the general way in which the reference variables set by steering institutions adapt over time in response to social feedback. The expression can be altered, however, depending on the context and problem at hand. For example, consider the following variant, assuming that $\sigma \neq 0$:

$$\begin{aligned} w_{t+1} &= w_t + \sigma\left(\hat{w}_t - w_t\right) + \gamma_t \quad \text{if } |\hat{w}_t - w_t| \geq \bar{w} \\ w_{t+1} &= w_t + \gamma_t \quad \text{if } |\hat{w}_t - w_t| \prec \bar{w} \end{aligned}$$

This formulation suggests that the steering institution is amenable to changing the reference variable in response to social feedback only if the magnitude of $\hat{w}_t - w_t$ passes a critical level. Assuming $\gamma = 0$, this allows for the reference variable to remain unchanged till $t + j$, when the divergence of the reference variable from that desired by society exceeds the critical level. For example, as suggested by Williamson (2000; see Sect. 3.1), some institutions (such as social institutions) are slower to change than others. Setting a higher critical level helps capture this feature.

Given w_{t+1}, the steering institutions would have to send an actuating signal that enables a change in the output realized in time t, y_t, to the output it desires in period $t + 1$, w_{t+1}. The 'error' is then the difference between the two; in other words:

$$e_{t+1} = w_{t+1} - y_t$$

The error term captures the change in output that the steering institutions desire to control for in the following period through a change in their signal level to the social actuators. It will be recalled from Sect. 2 that the steering institutions can control the output only through a low-powered actuating signal, with the social mechanism effecting the actual change in output. The actuating signal required to bring about the change e_{t+1} is in the first instance proportional to e_{t+1}, so that a greater change requires a higher signal. For example, if a central bank desires a large decrease in inflation, it must signal this with a greater increase in the interest rate (the actuating signal). The specific proportional link between the desired change in output and the actuating signal can be described as:

$$u^{\mathbb{P}}_{t+1} = \mathbb{P}e_{t+1}$$

The constant of proportionality $\mathbb{P}$ is referred to as the proportional gain in control theory. In our context, we can interpret $\mathbb{P}$ as the sensitivity of the steering institutions' response to a given error. Consequently, the higher the value of $\mathbb{P}$, the greater the response of the steering institutions to a given error, and therefore the greater the stimulus to the plant to effect a change in output. As can be imagined, a $\mathbb{P}$ that is too high will result in an unstable system where the output produced by the plant overshoots the desired mark due to excessive stimulus from the steering institutions.

In an engineering system, the proportional tuning carries the bulk of the tuning adjustments by a controller. However, since it only corrects the immediate error in the system, it is quite possible that even in a steady state an error persists. Persistent error of this sort is corrected by adjusting the tuning for past error, which is the purpose of the integral component of the tuning process. In our context, this corresponds to a situation where steering institutions have a memory for past errors, and use that memory to reduce persistent errors. Specifically, this adds a term to the actuating signal:

$$u^{\mathbb{I}}_{t+1} = \mathbb{I}\sum_{i=0}^{t} e_i$$

Here, the constant $\mathbb{I}$ is the integral gain, and has a similar interpretation to $\mathbb{P}$. While integral control allows a memory for past errors, if the gain is too high, it can result in an output that oscillates about the reference and, and the longer the memory for errors is factored into the tuning process, the more likely this is to occur.

In situations where the reference variables change often, and in large magnitude, as can often occur in a social, economic or political situation, proportional and integral tuning may generate responses that are too slow or subject to overshooting targets. To facilitate a quicker and smoother response, a derivative component can be added to the tuning process, where the current error is compared to the previous one. A rapid change in the error can thus be compensated for by the steering institution while generating an actuating signal. Particularly, derivative tuning can be viewed as a linear extrapolation of past errors. The derivative term can be summarized as:

$$u_{t+1}^{\mathbb{D}} = \mathbb{D}(e_{t+1} - e_t)$$

The overall actuating signal generated by the steering institution is then the sum of the three components:

$$u_{t+1} = u_{t+1}^{\mathbb{P}} + u_{t+1}^{\mathbb{I}} + u_{t+1}^{\mathbb{D}}$$

Depending on the level of information gathered by the steering institution and the specific context under analysis, we expect that a steering institution would use some combination of the three components, say PI or P only or PID, to tune the output.

5 Concluding remarks

The behavior of institutions has received extensive analysis from the different disciplines of the social sciences. Much of this literature tends to be retrospective, often analyzing the historical relevance of institutions to societies, the nature of their influence over societies and even their very historicity. Our motivation for the idea of smart institutions expressed in this paper was a desire to construct a forward-looking methodology for institutional analysis that enables the consideration of institutions as social constructs transcending any of the social sciences in isolation, and yet can be understood using formal and tractable constructs.

Institutions evolve, but they often also need to be designed with an eye on their relevance to the context within which they exist. To assist in this ambition, we present a theory for smart institutions, inspired by control process engineering, that is capable of handing many of the features that are central to the characterization of real-world institutions. Inherent in this characterization is an element of dynamism, where institutions are affected by social feedback on change they help foster. Institutions can receive information from a wide variety of sources and of varying degrees of quality ranging from crisp quantitative data to fuzzy qualitative feedback. The ability to incorporate all these types of information in a single analytical framework and to provide some understanding of what constitutes useful information for institutions is, we believe, one of the primary strengths of the smart institutions theory. Given the complexity of this exercise, we have drawn a fine balance between analytical rigor that forms the backbone of control process engineering and the intuition that is necessary to understand social science phenomena.

Our goal in this paper has been to lay the skeleton for an analytic interdisciplinary approach to institutional analysis. Certainly, this skeleton has to be fleshed out depending on the context of analysis. However, in this endeavor we have the benefit of a vast array of tools that control process engineers have developed to handle context-based modifications to the fundamental structure. While potential applications are as vast as the variety of social science contexts that exist, we conclude with three areas that form the basis of our current research applying the smart institutions methodology.

First, explicit modeling of the frequency with which the steering institutions adjust their actuating signals can be used to study inertia in institutional change, the cyclical patterns of such change and how they correspond to cyclical changes in output. To contextualize this even further with empirics, we could enquire how institutional change is linked to business cycles and how this varies across countries. Second, we view the balance between market and regulatory failure as effects of institutional output, and explore the idea of this balance being devised as the reference variable by steering institutions in a particular society. Third, we empirically investigate the use of fuzzy feedback by institutions. Overall, we hope that advances in control process engineering will benefit those of us who are fascinated by how institutions function.

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References

Acemoglu D, Johnson S (2005) Unbundling institutions. J Political Econ 113(5):949–995
Acemoglu D, Johnson S, Robinson JA (2005) The rise of Europe: Atlantic trade, institutional change and economic growth. Am Econ Rev 95(3):546–579
Aghion P, Algan Y, Cahuc P, Shleifer A (2010) Regulation and distrust. Q J Econ 125(3):1015–1049
Coase R (1960) The problem of social cost. J Law Econ 3:1–44
Doucouliagos H, Ulubasoglu MA (2008) Democracy and economic growth: a meta-analysis. Am J Political Sci 52(1):61–83
Glaeser EL, La Porta R, Lopez-De-Silanes F, Shleifer A (2004) Do institutions cause growth? J Econ Growth 9(3):271–303
Goorha P (2009) An evolutionary approach to revising modernization theory: an introduction to the credible polity. World Futures 65(3):176–203
Grossman SJ, Hart O (1986) The costs and benefits of ownership: a theory of vertical and lateral integration. J Polit Econ 94(4):691–719
Grossman G, Helpman E (1994) Protection for sale. Am Econ Rev 84(4):833–850
Jaynes ET (1957) Information theory and statistical mechanics. Phys Rev 106(4):620–630
Klein B, Crawford RG, Alchian AA (1978) Vertical integration, appropriable rents, and the competitive contracting process. J Law Econ 21(2):297–326
Mohan V, Goorha P (2008) Competition and unitization in oil extraction: a tale of two tragedies. Rev Law Econ 4(1):519–561 **(Article ID 24)**
North D (2010) Understanding the process of economic change. Princeton University Press, Princeton
Olson M (1965) The logic of collective action: public goods and the theory of groups. Harvard University Press, Cambridge
Ostrom E (2010) Beyond markets and states: polycentric governance of complex economic systems. Am Econ Rev 3:641–672
Persson T (2002) Do political institutions shape economic policy? Econometrica 70(3):883–905
Portes A (2006) Institutions and development: a conceptual reanalysis. Popul Dev Rev 32(2):233–262
Putnam R (1993) Making democracy work. Princeton University Press, Princeton
Rodrik D, Subramanian A, Trebbi F (2004) Institutions rule: the primacy of institutions over geography and integration in economic development. J Econ Growth 9(2):131–165
Rodrik D (2008) Second-best institutions. Am Econ Rev 98(2):100–104
Tsebelis G (1995) Decision making in political systems: veto players in presidentialism, parliamentarianism, multicameralism and multipartyism. Br J Polit Sci 25(3):289–325
Williamson OE (1975) Markets and hierarchies: analysis and anti-trust implications—a study in the economics of internal organization. Free Press, New York
Williamson OE (2000) The new institutional economics: taking stock, looking ahead. J Econ Lit 38(3):595–613
Williamson O (2009) Pragmatic methodology: a sketch, with applications to transaction cost Eeconomics. J Econ Methodol 16:145–157