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The effects of political short-termism on transitions induced by pollution regulations*

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Abstract We study the dynamic problem of pollution control enacted by some policies of regulation and mitigation. The transition dynamics from one level of regulation and mitigation to another usually involve inter-temporal trade-offs. We focus on how different policymaker's time horizons affect these trade-offs. We refer to shorter lengths in policymaker's time horizons as political short-termism or inattention, which is associated with political economy or information constraints. Formally, inattention is modeled by using Nonlinear Model Predictive Control. Therefore, it is a dynamic concept: our policymakers solve an inter-temporal decision problem with a finite horizon that involves the repetitive solution of an optimal control problem at each sampling instant in a receding horizon fashion. We find that political short-termism substantially affects the transition dynamics. It leads to quicker but costlier transitions. It also leads to an under-evaluation of the environmental costs that may accelerate climate change.

1. Introduction

As widely stated now, anthropogenic pollution resulting from economic activity has been observed for a long time.[1] Pollution is a by-product of economic activity and has adverse effects on welfare. In the short run, the adverse effects on welfare are mitigation costs - costs of controlling pollution - and in the long run, there is cost arising from social, ecological, and economic damages resulting from the greater pollution. Nevertheless, in the long run, there are likely to be also welfare gains. Nordhaus (1992, 2014), and Bonen *et al* (2016), Orlov *et al.* (2018) provide an explicit treatment of both the mitigation and adaptation costs.[2]

Although an equilibrium between long-run costs and benefits can be achieved, regulation standards must change over time. For example, some technologies become obsolete, and policymakers find it optimal to disincentive their use. By contrast, new technologies substitute the old ones and need to impose new regulation standards. Moreover, regulation standards can be used strategically to incentivize innovation to more efficient production techniques.[3]

In both cases, the regulator faces transitioning from one type of regulation to another. Moving from one standard to another is a dynamic process with high transition costs.

In this paper, we are dealing with dynamic transitions involved in changes in regulatory standards. Therefore, we mainly deal with mitigation rather than adaptation costs. However, policymakers are constantly subjected to a trade-off in emission

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[1] See Spengler and Sexton (1983) and Gallegati *et al.* (2017) for the nexus of economic growth, C02 emission and global temperature rise. For the nexus of CO2 emission, climate disasters and adaptation policies, see Mittnik et al. (2018).

[2] Orlov *et al.* (2018) show that, indeed, the agents in the short run, the current generation, might face some welfare losses, as compared to business-as-usual. Still, in the long run, for future generations, there can also be some gains since increases in temperature and damages are avoided.

[3] See, e.g., Porter (1991), Gore (1992), and Porter and van der Linde (1995).

regulations in the short run. Specifically, we look at trade-offs in the well-known pollution control problem in transitioning from one level of regulation and mitigation to another. Furthermore, we focus on how different policymaker's time horizons affect these transitions. We refer to shorter lengths in policymaker's time horizons as political short-termism or policy inattention.

Determining the optimal path of emissions requires the solution of an optimal control problem (Nordhaus, 1992, 2014). In our setup, political short-termism is modeled using Nonlinear Model Predictive Control (NMPC). Unlike the traditional optimal control, NMPC does not involve a maximization over the entire planning horizon. It instead involves the repetitive solution of a dynamic decision problem at each sampling instant in a receding horizon fashion (Grüne *et al.*, 2015). We interpret a shorter horizon as measuring inattention.

Along the above lines, we consider two polar scenarios. In the first one, somewhat resembling emerging markets, we assume that the policymaker aims to regulate pollution through technology, placing new standards of regulation, not to allow pollution to go above a certain level. In the second one, the regulator is supposed to bring down the pollution level to a lower level by moving from a high level of pollution to a lower one. It mimics the case of an obsolete technology being replaced by new technology, a case one might observe in advanced countries.[4]

Our main finding is that policy inattention substantially affects the transition dynamics. Present-centric policy thinking matters, i.e., it affects the transition dynamics, leading to quicker but more expensive transitions in both the case of growing emerging market economies and the case of advanced countries. Independently of the case considered, inattention always leads to an under-evaluation of the environmental costs. It means that inattention allows, in either of our two cases above, for a larger built-up of a pollution stock that is likely to threaten the threshold - the carbon budget - below which the current Paris agreement on the upper bound of temperature rise, namely 1.5 to 2 degrees Celsius, is not ensured.

Other recent researches use NMPC to study environmental problems. Greiner *et al.* (2014) study the transition of an economy from non-renewable to renewable energy. They study the conditions when a transition to renewable energy can occur and whether it takes place before non-renewable energy is exhausted. A socially optimal solution that considers the negative externality of non-renewable energy, in the long run, is considered. They also study how tax rates and subsidies can be used to mimic the optimal solution in a market economy.

Nyambuu and Semmler (2014) consider optimal extraction and production of non-renewable resources that are finite in quantity. They show an inverted hump-shaped path for the price and a hump-shaped path for the extraction rate in the case of the modest initial stock of proved reserves.

Weller *et al.* (2015) and Kellet *et al.* (2019) develop a receding horizon implementation of the Integrated Assessment Model (IAM) of climate economics (Nordhaus, 1992, 2014) and compute the social cost of carbon in the presence of uncertainty of future damages. Their receding horizon approach provides a decision-making framework to deal with key geophysical and economic uncertainties arising from the long-run pollution effects.

We use a similar approach as the above research but from a different perspective. Greiner *et al.* (2014), Nyambuu and Semmler (2014), Weller *et al.* (2015), and Kellet *et al.* (2019) use NMPC to mimic the dynamic programming solution and to obtain global solution without linear approximations. We instead use the NMPC approach to model policymaker's inattention. From this point of view, our paper is related to the pioneering studies of Buchanan and Tullock (1962: Chapter 4), Nordhaus (1975), and Simon (1995: 90), who emphasizes the question of time horizon and how policymaker's choices would be affected by it. For instance, when a government is almost certain to lose the coming election, it may leave a legacy of policies that ties the hands of its opponents.[5]

Recently, the idea of political short-termism was introduced by Di Bartolomeo *et al.* (2018) to study public debt dynamics in differential games. They find that short-sightedness induces policymakers to be initially more aggressive in stabilizing the debt, but it finally leads to excessive public debt in the long run. These initially too-aggressive policies inertially trap policymakers along a dynamic path consistent with high long-run debt. Others have investigated other effects of impatience, and discount factor shocks on policymakers' behavior (Niemann and von Hagen, 2008; Adam, 2011; Niemann, 2011; and Niemann *et al.*, 2013).

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[4] Note that the Paris agreement allows emerging markets a different path to a low carbon economy than advanced economies (see Task Force on Climate-related Financial Disclosures, 2017).

[5] Some examples are provided by Persson and Svensson (1989), Alesina and Tabellini (1990), and Chari and Cole (1993).

Alternatively, one can interpret the policymakers' different time perspectives in terms of limited capabilities of forecasting the effects of their policies. Policymakers, like other economic agents, often make decisions under limited information; they respond imprecisely to the continuously available information, face future uncertainties, or have limited information processing capacity (Simon, 1995, 1997).[6]

A prominent theory is a rational inattention proposed by Sims (1998). As long as processing information is costly, the agents may find it unreasonable to use all available sources of information. Instead, they would focus on selected sources and may rationally take their choices on incomplete information.[7]

The rest of the paper is organized as follows. Section 1 describes our framework and formally introduces the inattentive policymaker's idea. Section 2 presents our results, i.e., the interaction effects of inattention and environmental policies. Both cases of new - and old-technology regulation are introduced. Section 3 concludes.

2. A model of pollution control

Next, we present a more general model that allows studying the two cases above, of an emerging market economy with higher growth rates and an advanced matured economy with lower growth rates, with a long history of pollution.

2.1 The economic framework

Our general pollution control model is borrowed from Saltari and Travaglini (2016).[8] The model is based on a cost-benefit analysis of pollution.[9] Pollution is a by-product of economic activity, and emissions from economic activity negatively affect welfare. Therefore, a certain emission level is unavoidable; thus, producing goods and services may not be possible without generating some pollution.

Denoting the stock of pollution at time t by $p(t)$, the equation of motion that describes pollution dynamics can be written as the difference between the emissions ($z(t)$) and the ecological decay of the pollution stock ($\delta p(t)$):

$$(1) \qquad \dot{p}(t) = z(t) - \delta p(t)$$

where pollution decay is assumed to be a linear function of the pollution stock level. We can refer to (1) as the emission equation.

The policymakers aim to choose the level of emissions to maximize net social benefits that can be written in a compact form as:

$$(2) \qquad W(0) = \int_0^T e^{-\rho t}(B(t) - C(t))dt$$

where ρ indicates the discount rate; the interval $[0, T]$ represents the planning horizon; $B(t)=[\alpha p(t)]^{\theta}$ are the gross benefits; and $C(t)=z(t)+\omega z(t)^2/2$ are the gross costs.

Pollution is related to production and we can write the benefit, $B(t)$, as related to capital via pollution, $\alpha p(t)$. The specification used is consistent with a standard production function, where pollution is a by-product of the use of capital. The parameter $\alpha>0$ increases the effect of natural abatement and falls in the marginal propensity to pollute of the community; $\theta \in (0,1)$ increases in output elasticities of the production factor and falls in the elasticity of pollution.[10]

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[6] See also Deissenberg and Cellarier (1999), Dawid *et al.* (2005), Arifovic *et al.* (2010), and Hebert and Woodford (2017).

[7] See, among others, Sims (2005, 2006, 2010) and Woodford (2009). A complete survey on this issue is outside the scope of the present paper. Alternative interpretations could be based on externalities, troubles, or corruption (bribery). See, e.g., Accinelli *et al.* (2014), who formalize joint dynamics of corruption and pollution in a model of evolutionary game theory.

[8] We refer to them for derivation details. See also, e.g., Fisher *et al.* (1972), Kamien and Schwartz (1991), Dockner and van Long (1993), Kolstad and Krautkraemer (1993), Tahvonen (1995), Jorgensen *et al.* (2010), and Athanassoglou and Xepapadeas (2012).

[9] Cost-benefit analysis raises several methodological and theoretical challenges that are far beyond the scope of our paper. Palmer *et al.* (1995) and Pearce *et al.* (2006) provide a comprehensive discussion of cost-benefit analysis and policy applications.

[10] For a formal derivation, we refer to Saltari and Travaglini (2016). It is worth mentioning that we need to use discrete controls to introduce NMPC techniques in the setup developed by Saltari and Travaglini (2016). By contrast, for comparison, we assume the state variables evolve in continuous time.

The damages of emissions, $C(t)$, are nonlinear as they include an increasing quadratic term. Thus, the marginal adjustment cost is increasing in the size of emissions. The specification, $C(t)$, captures the idea that additional units of emissions increase more than proportionally the disutility endured by society. An acceleration of the emissions rate then increases the social costs of any incremental unit of pollution released.

2.2 *The policymakers' problem and inattention*

We first characterize the standard problem, then we introduce inattention. In both cases, denoting p_0 as the stock of pollution at the beginning of the planning horizon, we assume that the policymakers aim to implement a different level of pollution, i.e., p_F, defined by an agreed-upon carbon budget. During the transition from p_0 to p_F, constrained by the emission equation (1), the policymakers would choose a sequence of emissions that maximizes net benefits (2).

In a full information context, the behavior of the rational policymaker can be found by using the standard control theory tools to solve the net benefit maximization problem. Formally, our policymaker solves

$$\text{(3)} \qquad \max_{z(t)} W(0) = \int_0^T e^{-\rho t}([\alpha p(t)]^\theta - z(t) - \frac{\omega}{2} z(t)^2)dt$$

$$\text{s.t.} \quad \begin{aligned} &\dot{p}(t) = z(t) - \delta p(t) \\ &p(0) = p_0 \\ &p(T) = p_T \end{aligned}$$

The Hamiltonian for problem (3) can be easily derived and solved. We denote the (Rational Expectations) corresponding solution by $\{z^{RE}(t)\}_0^T$.

The solution of (3) using control theory is consistent with the idea that the length of the policy horizon is the result of myopia or limited rationality. Different lengths capture different policymakers' perspectives or constraints, for instance, the chances of survival in office by the government or some constitutional constraints. Following Di Bartolomeo *et al.* (2018), we can interpret a time preference for the short run against the long run as a measure of political instability, i.e., the frequency of government turnover, which depends on voter preferences, political institutions, and salient events and issues. Alternatively, we can assume that people often make decisions under limited information, respond imprecisely to the continuously available information, or have limited information processing capacity (Simon, 1990; Sims, 1998).

A way to model the above concept of rational inattention in a dynamic setting is to use NMPC (Grüne *et al.*, 2015). NMPC does not involve a maximization over the entire planning horizon. However, it involves the repetitive solution of an optimal control problem at each sampling instant in a receding horizon fashion. Then a shorter horizon can be interpreted as measuring stronger inattention.

We denote the choices of the policymaker operating under rational inattention by $\{z_N^{RI}(t)\}_0^T$, where $N<T$ is the degree of inattention. The emission at each time $\tau \in [0,T]$ is determined to optimize a performance index with a receding horizon. At each time τ, the optimal emission $z(\tau)$ is determined over the horizon $[\tau, \tau+N]$, solving

$$\text{(4)} \qquad \max_{z(t)} W(0) = \int_\tau^{\tau+N} e^{-\rho t}([\alpha p(t)]^\theta - z(t) - \frac{\omega}{2} z(t)^2)dt$$

$$\text{s.t.} \quad \begin{aligned} &\dot{p}(t) = z(t) - \delta p(t) \\ &p(\tau) = (\int_0^\tau z_N^{RI}(k) e^{-\delta k} dk + p_0) e^{\delta \tau} \\ &p(\tau+N) = p_F \end{aligned}$$

Then the optimal value at time τ ($z(\tau)$) is used as the actual input to the controlled system. Note that the initial condition ($p(\tau)$) of the problem (4) is obtained from the previous horizon solution.

Summarizing, the NMPC solution consists of the first optimal inputs of a series of control problems over a given (moving) horizon of length N.

3. Inattention and environmental policies

Specific-country considerations drive environmental policies and desired targets and trade-offs may differ across different economies. For instance, relevant differences arise between low-income countries and high-income countries. Stern and Stiglitz (2017: 19) emphasize how the imperative of development and poverty reduction may justify slower and more moderate emission reductions over the short term. Low-income countries, thus, could do less to reduce their emissions in the short term to ensure poverty reduction. Specifically, Stern and Stiglitz (2017) underline that low-income countries tend to have less ambitious objectives for emission reductions or to require a lower carbon price to achieve a given level of emission reductions.

Along the above lines, we consider two simple scenarios. In the first one, we look at the problem of the policymaker who faces the transition from a low pollution level to a higher, targeted level consistent with society's desired production. The scenario is consistent with a regulation policy of emerging economies or the regulation of new-introduced technologies that substitute some old obsolete ones. Formally, in this scenario, we assume $p_0<p_T$.

The second case describes the problem of a policymaker in a mature economy. Now, the policymaker should manage the transition from a high pollution level to a lower one for an obsolete technology that a new, most efficient one will replace. For a long time, both technologies can coexist. Thus, the policymaker could aim to regulate the old (inefficient) technology to be used less, reducing the associated pollution level.[11]

The second scenario is characterized by $p_0>p_T$.

We refer to the first scenario as the case of "growth and pollution regulation" and to the second as the case of "obsolete technology and pollution abatement." In both scenarios, the model is solved by numerical simulations.[12]

We calibrate the model by using a reasonable set of parameter values. The annual discount factor ρ is set at 0.04 (corresponding to a 4% rate). The ecological decay of the pollution stock is 5% per year (i.e., δ=0.05). The other parameters are ω=1, θ=0.3, and α^{θ}=0.5. These values are consistent with an elasticity ranging from about 0.3 to 3.3. Moreover, we assume that p_0=3 and p_T=14 in the first scenario, whereas p_0=45 and p_T=14 in the second.[13]

We compare the optimal regulation designed by a rational policymaker (i.e., problem (3)) to inattention (i.e., problem (4)), which is captured by different values for the policymaker's (moving) horizon of length N. Specifically, we consider three different cases: strong inattention; inattention; weak inattention (respectively, length equal to 90, 110, 130). The value for T is set at 160; therefore, the planning horizon for the rational policymaker is [0,160].

3.1 Growth and pollution regulation

New technologies replace old ones, and one must impose regulation standards. Therefore, the policymaker faces a transition from one level of regulation to another one. Specifically, the regulator faces the problem of moving from an initial low level of pollution and production to an upper-bound standard compatible with the desired growth rate. Our results are illustrated in Figure 1. The path depends on the regulator's inattention. The solid line represents the case of an attentive policymaker.

During the transition dynamics, optimal emission regulation requires achieving the desired standard gradually. In the absence of inattention, the optimal control solution requires an "overshooting policy," resulting in reversed-hump-shaped emission dynamics (Saltari and Travaglini, 2016). The emissions are initially reduced, and only at about the mid-planning horizon do they. Then, they start to converge to the desired standard. The rationale of the dynamics is due to the high social cost of pollution. Similar optimal dynamics hold for the extraction and production of non–renewable resources (e.g., Nyambuu and Semmler, 2014).

How does inattention affect the policymaker's decisions? First, as inattention increases, the regulator tends to reach the desired standard faster while underestimating the impact on the environment during the transition.

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[11] We focus on the regulation of the old obsolete technology. Clearly, the case of the new efficient one is already described by the first scenario.

[12] NMPC is implemented following Grüne *et al.* (2015) and using the Matlab routines developed by Grüne and Pannek (2017).

[13] For the sake of comparison, we use the same parameters proposed by Saltari and Travaglini (2016). However, our findings are qualitatively robust to changes in the parameterization. Results are available upon request.

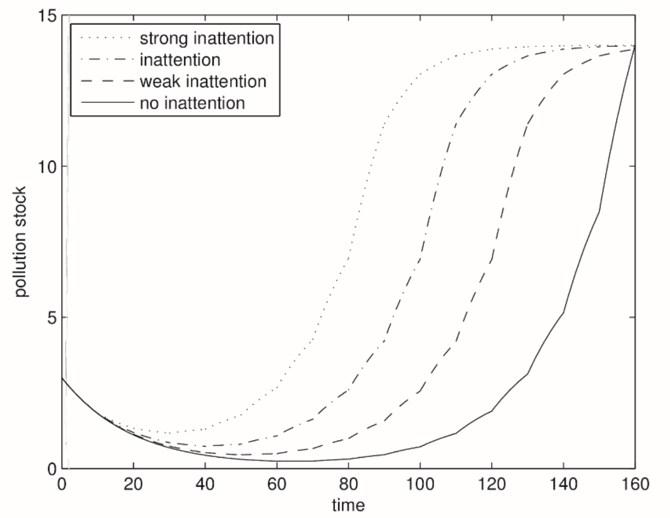

Fig. 1. Emission regulation path for a new technology

The average effects of inattention during the transition dynamics can be quantified. Table 1 reports them. The table also reports percent deviations from the rational expectation benchmark. Compared to the optimal control policy, strong inattention implies a pollution stock and average emissions about two times larger. Notable differences emerge for all cases of inattention.

Table 1. Effects of inattention (new technology)

	pollution (stock)		emission (flow)	
	average	%	average	%
Strong inattention	8.37	167	0.46	172
Inattention	6.76	115	0.37	121
Weak inattention	5.13	63	0.28	69
No inattention	3.14	-	0.17	-

Thus overall, inattention and short-sightedness allow for a more considerable build-up of a pollution stock that is like to threaten the threshold, adjusted for developing economies, below which the carbon budget and the current Paris agreement on the upper bound of temperature rise are not ensured.

3.2 Obsolete technologies and pollution abatement

The effects of introducing a new technology that makes the old one (more polluting) obsolete are illustrated in Figure 2. This is more common in advanced countries that have long used fossil fuel energy. Such old technology is assumed to be regulated to bring pollution down to a lower level. Figure 2 describes the transition from a soft standard (associated with a high pollution level) to a demanding standard. The path depends on the regulator's inattention. The solid line represents the case of an attentive policymaker again.

During the transition, optimal policies must quickly abate the pollution level to converge to lower levels, to the new desired standard. As inattention increases, the policymaker will again tend to reach the desired standard faster but at a higher cost. As a result, the regulator again under-evaluates the environmental impacts of the transition to the new desired standard.

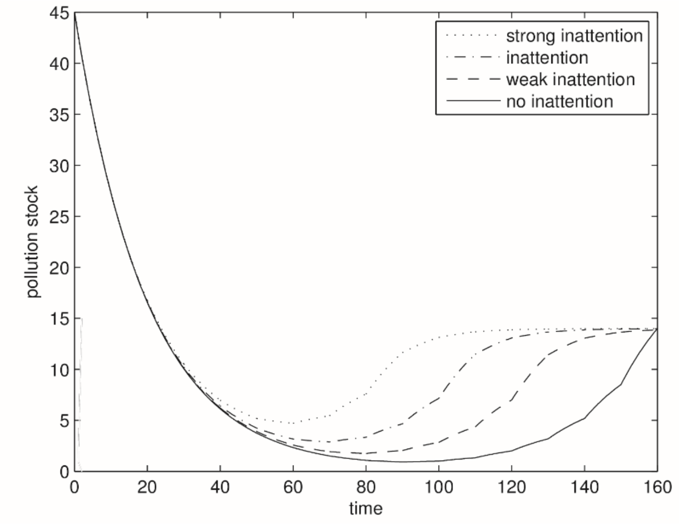

Fig. 1. Emission regulation path for an obsolete technology

The average effects of inattention during the transition dynamics of the regulation of an obsolete technology are described in Table 2. The table reports the average pollution, emission, and percent deviations from the rational expectation benchmark.

Table 2. Effects of inattention (obsolete technology)

	pollution (stock)		emission (flow)	
	average	%	average	%
Strong inattention	13.98	58	0.45	170
Inattention	12.41	41	0.37	120
Weak inattention	10.80	22	0.28	68
No inattention	8.81	-	0.17	-

Here too, inattention and short-sightedness allow for a more extensive build-up of a pollution stock that threatens the threshold for advanced economies, below which the carbon budget, and the current Paris agreement on the upper bound of temperature rise, is not ensured.

4. Conclusions

We studied the effects of the regulator's inattention in the transition from two different levels of environmental regulation. We can refer to political short-termism or policy inattention as shorter lengths in policymaker's time horizons. The rationale of different time perspectives can be found in policy uncertainty, institutional constraints, or limited rationality due to limited information or rational inattention.

Independently of its rationale, policy inattention was modeled by using nonlinear model predictive control. In each instant of time, the regulator can solve an optimization problem considering the effects of the policy for a limited horizon. A shorter horizon is interpreted as a measure of inattention. Of course, as time passes, the regulator revises the plan forward. The NMPC approach provides a principled decision-making framework to deal with policymakers' inattention, which complements the existing models based on optimal control methods.

Our main result is that no matter whether the regulator designs a plan to achieve a lower (fast-growing emerging market economies) or higher level of emission standard (advanced countries with old energy technology), political short-termism leads to quicker but more expensive transitions associated with an under-evaluation of the environmental risk. Hereby the targeted upper limits of emissions and temperature are threatened not to be ensured.

Appendix

Both problems (3) and (4) are solved by maximizing one (or more Hamiltonians) of the following kind:

(a1) $$H(k) = e^{-\rho t}\left([\alpha p(k)]^{\theta} - z(k) - \frac{\omega}{2} z(k)^2 + \mu(k)[z(k) - \delta p(k)] \right)$$

with $k \in [k_L, k_U]$, $p(k_L) = p_{k_L}$, and $p(k_U) = p_{k_U}$, which requires

(a2) $$\frac{\partial H(k)}{\partial z(k)} = 0 \Rightarrow -1 - \omega z(k) + \mu(k) = 0$$

(a3) $$\dot{p}(k) = \frac{\partial H(k)}{\partial \mu(k)} \Rightarrow \dot{p}(k) = z(k) - \delta p(k)$$

(a4) $$\dot{\mu}(k) = \rho \mu(k) - \frac{\partial H(k)}{\partial p(k)} \Rightarrow \alpha^{\theta} \theta p(k)^{\theta - 1} = (\rho + \delta)\mu(k) - \dot{\mu}(k)$$

The optimal policy plan stemming from (3) needs to solve (a2)-(a3) imposing $p(k_L) = p_0$ and $p(k_U) = p_F$. By contrast, the solution of (4) is obtained by solving a series of equations (6)-(7), at each instant of time $k \in [0, T]$, while $z_N^{RI}(k)$ is obtained by solving (6)-(7) imposing $p(k_L) = (\int_0^{k_L} z_N^{RI}(i) e^{-\delta k_L} di + p_0) e^{\delta k_L}$ and $p(k_L + N) = p_F$.[14]

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[14] The representation of the NMPC in continuous time models is not intuitive. From a practical point of view, NMPC requires to convert these models into a discrete time by sampling (for details, see Grüne and Pannek, 2017: 16-28).

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