# Dealing with the Obsolescence of Transport Infrastructure in Public-Private Partnerships[1]

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Abstract

We study how PPP contracts should allocate the risk that an infrastructure asset becomes obsolete and must be replaced or revamped. We argue that taxpayers should bear obsolescence risk. We also show that the economy-wide real effects of obsolescence go beyond the allocation of obsolescence risk and are the same whether the infrastructure is procured under traditional provision or a PPP.

To deal with obsolescence the public authority must have the option to unilaterally buy back the PPP. To avoid opportunism, the price should be equal to the present value of the net cash flows that the concessionaire would have received, had the asset not become obsolete. With both availability and present-value-of-revenue contracts the price can be calculated at any moment with accounting information verifiable before a court. This buyout clause gives the public authority as much flexibility as traditional provision and transfers obsolescence risk to taxpayers.

Keywords: obsolescence, transport infrastructure, autonomous vehicles, climate change

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## 1. Introduction

Public-Private Partnerships (PPPs) spread around the world in recent decades and have become an accepted means to procure transport infrastructure projects.[5,6] Projects that require large sunk, up-front investments, such as highways, bridges, seaports, airports and rails, which used to be provided almost exclusively by governments, are now often provided by private firms.[7]

A PPP bundles the financing and construction of the infrastructure asset with the provision of the service in a single long-term contract. In a typical build-operate-and-transfer (BOT) PPP contract, a public authority plans and designs the infrastructure asset and puts the concession to tender. Then a special purpose vehicle (SPV), owned by private investors, finances and manages construction, maintains and operates the asset for a long time (usually between 20 and 50 years) and, at the end of the contract, transfers it back to the government. During the operation phase, the SPV receives a stream of payments to cover the initial investment (the so-called capital expense or capex) and operation and maintenance costs (the so-called operation expense or opex). Depending on the project and type of infrastructure, the PPP may be funded with user fees, tax-funded payments made by the public authority or by a combination of both.

PPPs are subject to several well-known risks.[8] Some, like those wrought by construction, availability and maintenance, are controlled by the concessionaire, who can manage them. Other risks, like exchange rate swings or an earthquake are exogenous, but there are deep markets that insure them. Last, demand risk seems to be a category on its own: it is largely exogenous, but there are no well-developed markets to insure against it.

While there has been a lively controversy in the literature about how to best allocate and manage these risks, they are nonetheless considered inherent to a PPP contract. It is understood, therefore, that they must be allocated project by project in the contract, and that conflict

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[5] There exist three broad alternative organizational forms to provide infrastructure: traditional provision, PPPs (or concessions) and privatization, perhaps under a regulated monopoly. Each one of these forms allows a number of contractual arrangements. See Engel et al. (2014a, chapter 4).

[6] For example, in Europe PPP investment rose from almost zero in 1990 to almost €30 bn in 2006 (before falling by one third in the aftermath of the financial crisis; see Engel et al., 2014a). Similarly, in low and middle income countries, PPP investments rose from less than $20 bn p.a. in the early 1990s to between $50 bn and $90 bn p.a. in recent years (see Engel et al. 2014b). As Engel et al. (2014b, Table 1) show, nearly three quarters of PPP investment is spent in transport infrastructure--- mostly highways, but also bridges, tunnels, railways, airports, and seaports.

[7] Between 2008 and 2010 total yearly transport infrastructure spending reached about $1,040 bn: $80 bn in airports, $110 bn in seaports, $400 bn in rail and $450 in roads (rail spending includes rolling stock). See Engel et al. (2014b, Table 1). World PPP spending in transport PPPs varied between $45 bn and $75 bn per year.

[8] See, for example, Engel et al. (2014a and 2015) and Irwin (2007). By "risk" we mean a variable whose outcome affects total project value and whose realization is not known when deciding whether to go ahead with the project. To allocate a particular risk is to determine the extent to which each party bears unpredictable variation in total project value arising from unpredictable variation in that risk. To avoid confusion, we will not use the term "uncertainty". Frank Knight (1921) famously distinguished between quantifiable risk and non-quantifiable uncertainty. While this is a classic (if polemical) distinction, distinguished authors seem to ignore it (for example, Arrow and Lind (1970) use uncertainty in the title of their famous paper, but then use several classic theorems of probability theory to derive their results; similarly, Laffont (1989) uses the term uncertainty in the title of his classic text, but according to Knight he analyses risk. More important, the distinction is not really relevant for the analysis that follows. Also, by "risk" we do not mean "a loss larger than expected."

resolution mechanisms and institutions, like the courts or arbitration panels, should deal with the tensions and ambiguities that emerge when risks realize. Indeed, the PPP contract design literature deals exactly with these questions.

Transport infrastructure assets, particularly roads, bridges and tunnels, may also become obsolete---the physical asset may become inadequate to provide the required services, years before the PPP contract ends. A typical case is when demand growth exceeds expectations and capacity expansion becomes necessary well before the current contract expires. Moreover, and perhaps more important, several recent developments seem to have increased the probability that existing transport infrastructure assets may become obsolete or even useless in the next decades.

One is that autonomous vehicles will probably spread in the next 20 years, and affect both the demand and the supply for transport infrastructure.[9] On the demand side, little is known about how autonomous vehicles will affect user behaviour, inter-modal splits and travel patterns. On the supply side, autonomous vehicles will use space better, thus increasing the productivity of infrastructure and effective supply, ceteris paribus. Many believe that congestion will fall, and there will be overcapacity. And, perhaps more important, autonomous vehicles might interoperate among them and with the roads that carry them. Therefore, data communication and processing might become part and parcel of the design and day-to-day operation of roads.[10] It is an open question whether existing transport infrastructure may be adapted or will be incompatible with interoperability. However the case, it seems that new investments will be substantial and that in their current condition transport infrastructure will not provide the services standard that autonomous vehicles will require.

A second source of obsolescence is climate change and the need to adapt to it. On the demand side, taxes and standards on fuels will affect the cost of traveling and user behaviour, inter-modal splits and travel patterns. On the supply side, adapting to new and more stringent environmental standards and targets and to the effects of climate change may require revamping existing infrastructure or, in some cases, to build new infrastructure to replace the obsolete one. Severe weather shocks may also irreversibly damage existing infrastructure, just as earthquakes may do.

Contrary to most of the risks that have concerned policy makers so far however, obsolescence is hard to manage within existing BOT contracts. One reason is that its realization should lead to the early termination of the concession contract. Nevertheless, most contracts are not designed to deal with early termination.[11] Also, when dealing with major shocks like the

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[9] On autonomous cars see Bansal, et al. (2017), Bösch et al. (2018), Daziano et al. (2017), Fagnant and Kockelman (2015), Habouch et al (2017), Kruger et al. (2016), Lyons (2018), Shin et al. (2015), Wadud (2017), Wadud et al. (2016), and Zhang et al. (2018).

[10] See, for example, Funk (2015), Martínez, L. (2015), Veryard (2017), Walker-Smith, B., (2012), Winston and Mannering, (2014). On the governance of smart mobility see Docherty et al. (2018).

[11] In France contracts include three termination clauses. First, the so-called public good termination (art. 37.3 of the contract). This clause applies when the State decides to end the contract before the term of the PPP. The compensation principle is to pay the value that the company could have obtained if sold in the market---the present value of the net future cash flows that the PPP would have generated. Second, *force majeure* (art. 37.1 of the contract). This applies in very rare events that are beyond the concessionaire's control. The compensation principle is to pay for incurred costs and the incremental cost borne because of the rare event, but not compensate for lost earnings. Third, termination (art 40 of the contract). This applies when the concessionaire does not abide by the terms of the contract. In the event of termination, the concessionaire loses its equity and part of the debt.

introduction and diffusion of autonomous vehicles and climate change, policy must respond beyond the concessions directly hit by obsolescence, because large investments in new infrastructure become urgent. Last, both technological and climate change are aggregate shocks that will simultaneously and protractedly and affect many concessions and, indeed, most transport infrastructure assets. This will strain public budgets.

Consequently obsolescence raises three questions. One is who should bear the capital loss wrought by obsolescence; in other words, who should sell insurance to whom. Second, which contract distributes this risk appropriately and facilitates a smooth early termination of the PPP contract. And, last, which are the policy responses needed to deal with the consequences of obsolescence.

One of the main conclusions of this paper is that obsolescence risk --- the fact that the original PPP will not generate the cash flows promised to the concessionaire in the original contract--- is mainly a contractual and distributive issue between the concessionaire and the government. At the same time, the concern of policy makers should be to deal efficiently with the real effects of obsolescence. Therefore, from the point of view of policy makers, obsolescence risk is only part of a broader policy problem, namely how to optimally deal with the consequences of obsolescence shocks and adapt to them.

To see why, note that the concessionaire views obsolescence risk as a drastic fall in the ability of the infrastructure asset to produce the expected cash flows under the original terms of the contract. In a concession funded with tolls paid by users, the capital loss equals the present value of the tolls that users would have paid, had the asset not become obsolete. In a concession funded with payments from the budget, on the other hand, the capital loss is equal to the present value of payments that the government would have made to the concessionaire.

From the point of view of the economy, however, technological change and autonomous vehicles are ultimately not a threat, but an opportunity. Indeed, while users lose the surplus that they would have obtained using obsolete infrastructure, they gain an even larger surplus by using the new technologies and the new infrastructure. Thus, from the point of view of the economy and of policy makers, the key issue is how to replace or revamp the obsolete infrastructure optimally and avoid a disruption that might inefficiently postpone the adoption and roll out of the new technologies.[12]

Of course, climate change is likely to produce a capital loss to the economy. Nevertheless, as with technological change, it also requires a smooth transition to the new infrastructure and disruptions will be costly. Similarly important, from the point of view of the economy the important quantity is the net social cost or benefit of the obsolescence.

That said, the specific distribution of obsolescence risk and the capital loss between the concessionaire and taxpayers will affect efficiency for two reasons. One is that the consequences and timing of obsolescence are uncertain and perhaps unknown and there are no formal markets to trade obsolescence risk. Consequently, investors asked by governments to bear obsolescence risk will charge an insurance premium. Is this premium higher or smaller than the cost that taxpayers incur when they bear obsolescence risk?

The second reason why the allocation of obsolescence risk affects efficiency is that, as experience suggests, the outcome of contract incompleteness is almost inevitably a protracted legal dispute. Legal disputes are costly by themselves but, in addition, they will probably retard the adaptation of transport infrastructure to technological and climate change. One important reason

[12] By "optimally" we mean that adjustment costs exist and should be factored into the policy response to obsolescence.

is that the concessionaire may dispute the terms of the agreement either because it won't obtain the same revenue as under the concession or because it senses that the public authority has much to lose if an agreement is delayed. Regardless of the terms of a dispute, delays cause large welfare losses.

How should one deal with obsolescence risk? One rather radical alternative is to do away with private participation in transport infrastructure altogether and return to traditional provision. As Martimort and Straub (2016) have shown recently, large and uncertain risks such as climate change increase the relative attractiveness of traditional provision because the government enjoys more flexibility to adapt to it. And indeed, traditional provision gives the government full flexibility to adapt to obsolescence and deal with it. Moreover, as our analysis implies, obsolescence risk is a distributional matter: for example, if taxpayers bear it, they transfer money to the concessionaire, but that transfer does not affect the aggregate wealth of the economy. Therefore, from the point of the economy, it is less relevant than the real effects of obsolescence. With traditional provision and current budgetary accounting conventions, by contrast, the apportionment of the costs and benefits of obsolescence are not an issue because there are no explicit cash transfers involved.

One of the conclusions of this paper, however, is that there is no *prima facie* reason to prefer traditional provision to PPPs on the basis of flexibility and obsolescence risk allocation. We argue that, just as in traditional provision, obsolescence risk in a PPP should be borne by taxpayers and show that that there exist PPP contracts that arguably give the public authority as much flexibility as traditional provision regardless of the funding source of the infrastructure. The trick is to design the PPP contract so that the public authority can buy back the PPP by paying a verifiable price that appropriately compensates the concessionaire for the early termination.

Our argument starts from the observation that obsolescence risk is exogenous and beyond the control of the concessionaire or the public authority. Therefore, as Hall (1998) noted, the party that bears exogenous risk sells insurance to the party that is relieved of it. The literature has not produced compelling empirical studies showing that one or the other option is cheaper, however. Still, we believe that are two reasons which make a defensible case for taxpayers to bear the risk of obsolescence.

One is simply that transport infrastructure is public, regardless of the means of procuring it. The natural benchmark is traditional provision and then taxpayers bear exogenous risks, regardless of the way the infrastructure is funded.[13] Indeed, as we show below, the PPP contract can be structured to replicate the risk distribution wrought by a public project.

The second reason, and more compelling one, is that in private infrastructure projects financed via project finance, take-or-pay contracts, which fully transfer demand risk to the taker of the service, are routine. Effectively, a take-or-pay contract implies that all demand risks are borne by the buyer of the infrastructure service. It is telling (and a market test) that in take-or-pay contracts, private providers do not sell any insurance against exogenous risks to the users of the infrastructure; on the contrary, exogenous risks are borne by the buyer of the infrastructure services. Because the structure of contracting in private infrastructure is an equilibrium outcome, and it informs that infrastructure providers do not tend to specialize in bearing the exogenous risks of the projects they build and operate, it suggests that the insurance costs less if the taker of the service bears the exogenous risks. The analogue in public transport infrastructure is that the party that buys the service---the government--- should also bear the exogenous risks through an analogue of a take-or-pay condition. This effectively transfers the exogenous risk to the taxpayer.

[13] The proof is in Engel et al. (2014a, Table 5.1).

The second contribution of this paper is to show that there exist PPP contracts such that the public authority can unilaterally buy back the concession at any moment at the "right" price, namely the present value of the net cash flows that the concessionaire would have received, had the asset not become obsolete. These contracts fully transfer obsolescence risk to taxpayers, and give the public authority as much flexibility to deal with obsolescence as traditional provision.

The idea behind the contracts is simple. Suppose for a moment that both the public authority and the concessionaire agree when they sign the PPP contract that a specific amount, call it $C(t)$, will be the "right" compensation at time $t$, and that $C(t)$ can always be determined with verifiable accounting information---hence, it is a number which is difficult to dispute in court. Then the PPP contract could give the public authority the unilateral right to terminate the contract at any time $t$ by paying $C(t)$ to the concessionaire---that is, the contract could give the public authority a call option to terminate the contract unilaterally.

Because the concessionaire and the public authority agree *at the beginning of the concession* that $C(t)$ will be the right compensation at time $t$ and $C(t)$ can be determined with verifiable accounting information, the concessionaire is covered against the public authority's opportunism. At the same time, the concessionaire bears no loss if the public authority buys back the concession, because it receives the same net revenue in present value. Last, because $C(t)$ is verifiable by assumption, it is hard to dispute in court.

Note that under such a termination clause the government has as much flexibility to deal with obsolescence as with traditional provision. Indeed, provided it pays $C(t)$ to the concessionaire, the government can act as if the original contract did not exist. Moreover, note that the contract fully transfers obsolescence risk to taxpayers.

Of course, this begs the question where to find $C(t)$. As we have shown in previous work, however, $C(t)$ exists if tax-funded PPPs are procured with an availability contract or toll-funded PPPs are procured with a present-value-of-revenue (PVR) contract.[14]

To see how these contracts work, consider an availability contract such that the public authority pays the concessionaire $\pi$ every year for a fixed number of years $T$. If $r$ is the discount rate set in the contract, then the present value of these payments at the beginning of the concession at $t=0$ is

$$\begin{aligned}\Pi(0) &= \pi\cdot\sum_{\tau=1}^{T}\frac{1}{(1+r)^{\tau}}\\ &= \frac{\pi}{r}\cdot\left(1-\frac{1}{(1+r)^{T+1}}\right).\end{aligned}$$

Moreover, at any point in time, the remaining present value of the payments is

$$\begin{aligned}\Pi(t) &= \pi\cdot\sum_{\tau=t+1}^{T}\frac{1}{(1+r)^{\tau-t}}\\ &= \frac{\pi}{r}\cdot\left(1-\frac{1}{(1+r)^{T-t}}\right).\end{aligned}$$

[14] See Engel et al. (1997, 2001 and 2013).

Now note that $\Pi(t)$ can be calculated with accounting information at any time *t*, for $\pi$, *r* and *T* appear in the contract. If the contract sets $C(t)=\Pi(t)$, then $\Pi(t)$ is the value of the call option at which the public authority can buy the contract back when obsolescence hits and the compensation is exactly "the present value of the net cash flow that the concessionaire would have received, had the asset not become obsolete." Hence, $C(t)=\Pi(t)$ transfers obsolescence risk to tax payers and adequately compensates the concessionaire.

Note, in addition, that if the contract is allocated in a competitive auction and *I* is the investment needed to build the infrastructure, $\Pi(0)=I$ would be the winning bid. Last, the value of the call option can be adjusted to take account of the fact that the concessionaire will spend less in operation and maintenance if the concession lasts less than *T* years.

Similarly, as we have shown in previous work, a PPP funded with tolls can be procured with a present-value-of-revenue (PVR) contract.[15] With a PVR contract the concession lasts until the concessionaire collects $\Pi(0)$, the present value of revenue agreed in the contract. Therefore, the term of the PPP is variable and adjusts endogenously so that the concessionaire receives the same revenue in all states of demand. More important, with a PVR contract, "the present value of the net cash flow that the concessionaire would have received, had the asset not become obsolete" can again be calculated with accounting data. And, as we have shown in Engel et al. (2001, 2013), the PVR contract can be implemented with a least-present-value-of-revenue (LPVR) auction awarding it to the firm that bids the lowest present value of revenue over the life of the concession.

The rest of the paper proceeds as follows. In section 2 we briefly present the basic economics of obsolescence and obsolescence risk. In section 3 we develop some basic principles of efficient risk allocation in PPPs, argue that taxpayers should bear obsolescence risk and show how to implement a PPP in a way that this risk transfer is achieved while the public authority retains as much flexibility as with traditional provisions. Section 4 presents three case studies.

## 2. The economics of obsolescence

### 2.1 Technology, climate change and the obsolescence of existing transport infrastructure

Like all assets, transport infrastructure may become obsolete---the asset may become inadequate to provide the services that users require. For example, autonomous vehicles may not work on obsolete roads; or a large shock, like the policies adopted to deal with climate change, may require substantial investments to adapt to new standards and regulations.

Until recently, however, obsolescence of transport infrastructure might have been considered an interesting theoretical possibility, but with little practical relevance. One reason is that technological progress in construction techniques and infrastructure designs has been gradual, and transport authorities have adapted to the normal cycle of investment, maintenance and revamping.[16] At the same time, with a few exceptions, the normal state of transport infrastructure in most countries seems to be of chronic undersupply and congestion.[17] Sudden

[15] See Engel et al. (1997, 2001 and 2013).
[16] Roads have improved over time, but their characteristics have changed little: a solid, compacted, and smooth surface of concrete or asphalt painted to indicate restrictions, and traffic signals that visually give instructions and convey information.
[17] See, for example, Ingram and Liu (1999).

falls in demand that empty roads, airports or seaports have been rather infrequent and in any case could be managed case by case. [18]

Nevertheless, several recent developments have increased the likelihood that existing transport infrastructure assets may become obsolete or even useless in the next decades. Consider, for example autonomous vehicles, which many think will spread in the next 20 years, and affect both the demand and the supply for transport infrastructure.

On the demand side, little is known about how autonomous vehicles will affect user behaviour, inter-modal splits and travel patterns. Autonomous vehicles will open a new world in transportation but it is still largely unknown how it will look like. Passengers will have free time while they travel and interior car design may adjust to allow passengers to work or be entertained while they move around. If so, travel time may become a benefit instead of a cost, thus affecting the net value of the infrastructure, radically changing the nature of transport and the decisions that users make.

On the supply side, autonomous vehicles will use space better, thus increasing the productivity of infrastructure and effective supply, ceteris paribus. Indeed, many believe that overcapacity will substitute for congestion, the more so if car sharing diffuses and reduces the need for parking space.[19] And, perhaps more important, autonomous vehicles and roads will become interoperable. Therefore, data communication and processing will become part and parcel of the design and day-to-day operation of roads.[20] [21] It is an open question whether existing transport infrastructure will be incompatible with interoperability or may be adapted to it. But however the case, it seems that new investments will be substantial and that in their current condition transport infrastructure will not provide adequate services.

A second source of obsolescence is climate change and the need to adapt to it. On the demand side, taxes and standards on fossil fuels and emissions will affect the cost of traveling and user behaviour, inter-modal splits and travel patterns. On the supply side, existing infrastructure will need to be adapted to the effects of climate change and more stringent environmental standards. Moreover, severe weather shocks may also damage existing infrastructure, just as earthquakes do.

However the source of obsolescence, "obsolescence risk" is a rather incomplete way of thinking about the effects of obsolescence. To see why, note that the concern of the concessionaire of an existing transport infrastructure is that obsolescence may cause a drastic fall in the ability of the infrastructure asset to produce the expected cash flows under the original

[18] Of, course, the world is also littered with white elephants and oversized infrastructure projects, but their cause is not obsolescence but poor evaluations, pork barrel politics and corruption. At the same time, fast-growing demand may make and upgrade of the infrastructure asset very valuable and delays costly; but that is not obsolescence.

[19] The capacity of a road is a function of speed limits, the distance that cars must keep between each other and the number and width of lanes and shoulders. Autonomous cars will be able to move faster, at shorter distances between them and will need narrower lanes.

[20] See Winston and Mannering, (2014).

[21] At the heart of an autonomous vehicle there is a drive computer that gets information from an array of sensors or ADAS system. An ADAS system combine ultrasonic sensors, radar, and a camera or LiDAR (the "sensor package") which feeds the drive computer. The drive computer then performs what is known as "sensor fusion" to assemble a comprehensive picture of the environment and can then make decisions such as identifying and choosing a path in light of the route chosen, traffic, nature of the street, and so on. The newest input source is vehicle to vehicle-pedestrian-infrastructure/ technology ("V2X"). This entails standards setting to ensure that all parties can share information.

terms of the contract. This capital loss is the obsolescence risk to be allocated between the concessionaire and taxpayers. By contrast, the goal of policy makers should to adapt to obsolescence so that the economy takes full advantage of technological progress or adapts to climate change at minimum cost. A correct distribution of the capital loss borne by the concession is, therefore, only part of the concern of policy makers. In what follows we decompose the effect of obsolescence and analyse the place of obsolescence risk in it.

### 2.2 Some basic facts about obsolescence and obsolescence risk

#### *2.2.1. The impact on the real economy*

To decompose the effect of obsolescence, we develop a simple example. Assume that an existing road is rendered obsolete by autonomous cars. Had it not become obsolete, the road would have yielded a social benefit equal to \$100 in present value, mainly the benefit that the users would have realized from mobility after paying for all private costs. At the same time, if the cause of obsolescence is technological progress, the social benefit will exceed the loss once the new infrastructure is revamped or built. For example, autonomous vehicles will increase the economy's output, as faster and smoother trips reduce the pecuniary costs of moving persons and freight. Moreover, space inside vehicles will be adapted for work or leisure, reducing the time cost of transportation. Assume that, once the infrastructure is revamped, autonomous vehicles generate a benefit to users equal to \$220. Last, in order to adapt to technological change, the existing piece of infrastructure must be revamped at a net cost of \$30.[22]

Let us now analyse the effect of obsolescence. Note that that the economy as a whole is richer by

$$\$90 = -\$100 + \$220 - \$30,$$

or

$$(\text{net social gain}) = -(\text{social capital loss, old}) + (\text{social capital gain, new}) - (\text{cost of revamping}).$$

Therefore −\$100 is the *social* capital loss wrought by obsolescence, for this is the impact of obsolescence on the social value of the existing road. Nevertheless, the concept is not very useful, because what matters is that, in order to get a gross social gain of \$120 (\$220 − \$100), the economy must invest \$30, and therefore, that the net social gain of adopting the new technology is \$90.

Analytically, there is little difference with climate change. To see why, assume that climate change destroys the existing infrastructure, which needs to be rebuilt at an incremental cost of \$40, and adaptations reduce the net benefit that users receive from using the infrastructure to \$80. Now the economy is poorer by

$$-\$60 = -\$100 + \$80 - \$40.$$

[22] This is an incremental social cost, equal to the cost of revamping the road to adapt to technological change, less the present value of the investments that would have been made had the existing road nor become obsolete.

Now what matters is that in order to minimize the social loss wrought by climate change, which equals \$20 (\$80 − \$100), the economy must invest \$40, so the total loss is −\$60 instead of −\$100. It is still the case that the *social* capital loss wrought by obsolescence is, by itself, largely a useless analytical concept.

### *2.2.2. The capital loss borne by the concession*

Let us now consider the concessionaire of the road that becomes obsoleteAt any given moment the value of a private asset is equal to the present value of the net cash flows that it can generate over its remaining economic life. A capital loss occurs when an event reduces this present value, and obsolescence is an extreme event that drastically and irreversibly reduces the ability of the asset to produce cash flows---indeed, the asset may not produce cash flows at all.

In the context of a PPP, then, obsolescence risk is the possibility of a drastic fall in the ability of the infrastructure asset to produce the expected cash flows under the original terms of the contract. In a concession funded with tolls paid by users, the capital loss equals the present value of the tolls that users would have paid, had the asset not become obsolete. In a concession funded with payments from the budget, by contrast, the capital loss is equal to the present value of payments that the government would have made to the concessionaire, had the asset not become obsolete.

In our simple example, assume that the concession would have generated \$45 in present value to the concessionaire in tolls or government payments: if the road becomes obsolete and the concession ends, this is the capital loss wrought by obsolescence.

Note that the capital loss wrought by obsolescence is largely a contractual and distributional issue: a contract implies that the concessionaire should have received \$45 had the road not become obsolete. However the road is funded, the key question when obsolescence hits is to what extent the concessionaire should bear the \$45 capital loss. This is largely a distributive issue.

Now the specific allocation of obsolescence risk may affect efficiency for two reasons. One is that the consequences and timing of technological and climate change are uncertain and perhaps unknown. Even more important, there are no deep markets to trade the risks that they create. Consequently, if governments ask investors in current private infrastructure projects to bear obsolescence risk, investors will charge an insurance premium. Is this premium higher or smaller than the cost that taxpayers incur when they bear obsolescence risk? We will deal with this question in the next section.

The second reason why the allocation of obsolescence risk may affect efficiency is that, as experience shows, the outcome of contract incompleteness is almost inevitably a protracted legal dispute. Legal disputes are costly by themselves, but in addition they will probably retard the adaptation of transport infrastructure to technological and climate change and increase the welfare losses wrought by obsolescence. With the help of our example, we now examine the welfare implications of contract incompleteness.

### *2.2.3 The real costs of contractual incompleteness*

As we have already said, technological change and autonomous vehicles will force the revamping of existing infrastructure. If the transition is smooth, users will realize the net benefits of technological progress soon. On the contrary, a protracted transition, in which concessionaires block the revamping of existing infrastructure, or governments try to avoid paying reasonable compensation, may postpone the benefits for many years, a net loss for the economy.

We can use our simple example to illustrate this point. In the example technological change created a net aggregate benefit of $90 (−$100 + $220 − $30). Assume now that disputes between a concessionaire and the government delay the transition. For example, the concessionaire knows that a delay is costly for politicians and he litigates to obtain a better deal. Then the existing infrastructure may still be used for a while, reducing the social capital loss from $100 to $90. Nevertheless, the delay reduces the benefits of technological change, say from $220 to $150. Thus the social benefit of technological progress falls from $120 ($220 −$100) to $60 ($150 − $90). Delays may be even costlier with climate change, which may damage existing infrastructure and make it unusable.

It follows that retaining flexibility to speed up the transition should be an important concern when designing PPP contracts. Note that under traditional provision a government has, in principle full discretion and control to revamp the asset. A PPP is, in principle, less flexible and therefore flexibility becomes an important issue when thinking of the relative merits of PPPs and traditional provision of infrastructure. We will return to this point below.

### *2.2.4 Financing, funding and the effect of obsolescence*

So far we have ignored one important question. Is traditional provision a better way to deal with obsolescence? As Martimort and Straub (2016) have shown recently, large and uncertain risks such as climate change increase the relative attractiveness of traditional provision because the government enjoys more flexibility to adapt to it. And indeed, in principle traditional provision gives the government full flexibility to deal with obsolescence. A different, but related question is whether the way of funding the infrastructure makes it easier or more difficult to deal with obsolescence.

Note first that the probability and magnitude of the social benefit or cost of obsolescence are the same, whether the infrastructure is public or provided via a PPP and whether it is funded with taxes or tolls. To see why, return to our road and assume that its probability of becoming obsolete is equal to $p$. [23] Clearly, the probability of being hit by obsolescence is exogenous of financing or funding.

Similarly, the social benefit of a road stems from the utility that users get from moving around. This benefit is independent of the means that the government uses to procure the road---the users of the road produce the same stream of social benefits, regardless of finance or funding; the same applies to the incremental infrastructure cost.

### *2.2.5 Obsolescence is a macroeconomic shock with fiscal implications*

Both technological and climate change are exogenous shocks that will affect the entire transport infrastructure network of a given country, no matter which parts are privately or publicly run. Therefore, public authorities will be forced to deal with obsolescence contemporaneously in most of the transport infrastructure network. Indeed, the obsolescence of transport infrastructure is a macroeconomic shock that will hit many countries simultaneously.

As we have seen, on the real side obsolescence will force governments to revamp existing infrastructure or replace it. On the fiscal side, therefore, obsolescence will strain budgets, as

[23] Note that the argument does not depend on probabilities being known, nor on Knight's distinction between risk and uncertainty. The capital loss will be the same with traditional provision and a PPP, regardless of the probability of the event.

governments seek to finance massive public spending in infrastructure. Our reasoning shows, in addition, that technological obsolescence wrought by autonomous vehicles is a wealth-creating macroeconomic shock. By contrast, obsolescence wrought by climate change most likely will reduce aggregate wealth---the economy will be poorer after the macroeconomic shock hits. Because economic growth increases tax revenues, managing a wealth-increasing shock is probably somewhat easier. But while spending in infrastructure will be upfront, the benefits of technological progress will realize only over time. Therefore, it may make sense to save and establish and fund an infrastructure fund to finance the buyback of the concession and the subsequent revamping.

The second implication is that obsolescence *risk* will affect a limited subset of infrastructure assets, those that are privately run. Because obsolescence risk will be correlated across concession within countries and across countries, however, it is unlikely that insurance markets will be willing to sell insurance against it. For this reason, it is an additional issue that policy makers will have to confront. We deal with this issue in the next section.

## 3. Dealing with obsolescence risk in PPPs

### 3.1 Allocating obsolescence risk in the PPP contract

#### *3.1.1. General principles of risk allocation in PPPs*

PPPs are subject to several well-known risks.[24] Some, like those wrought by construction, maintenance, and availability are controlled by the concessionaire, who can manage them; these are usually called endogenous risks. Other risks, like those caused by exchange rate swings or an earthquake, cannot be controlled, but there are deep markets where firms can insure against them. Demand risk, in turn, seems to be a category on its own: many times the concessionaire can do little against it, but there are no well-developed markets to insure it.[25] Last, some policy risks may be directly controlled by the authority in charge of the PPP, but other policy risks, while affected by the government, may be largely exogenous to the PPP.

How should the PPP contract allocate each risk between the concessionaire and taxpayers? Irwin (2007, p.14) stated the principle clearly: the contract should allocate risks to maximize project value, taking account of moral hazard, adverse selection and risk-bearing preferences---proper risk allocation is efficient and maximizes project value. This is a quite general principle,

[24] See, for example, Engel et al. (2014a and 2015) and Irwin (2007).

[25] Demand for using roads roads, tunnels and bridges is largely exogenous; provided that some minimum service standards are provided, the demand curve shifts in response to exogenous factors like the growth rate of the economy. By contrast, the concessionaire can significantly affect the demand for a port and for some airports. When the concessionaire can shift the demand curve by exerting effort and diligence it is, in general, a good idea to make him bear demand risk. In any case, whether demand varies endogenously or exogenously should be distinguished from two additional issues which are sometimes confused. One is whether the demand for the infrastructure responds or does not respond to price (these are movements along the demand for infrastructure services). If the demand responds to price, services should be optimally priced and price regulation must be an issue in the contract. The second is whether the infrastructure is a monopoly or can be made to compete with another infrastructure (for example two airports may compete for the same passengers and airlines or two ports/terminals may compete for the same shippers). If the infrastructure is a monopoly, price regulation may be in order.

however. To put some content into it is useful to distinguish between endogenous and exogenous risks.

#### *3.1.2. Endogenous risks*

Some project risks, like the cost of construction and maintenance or the availability of the infrastructure are endogenous, because the actions, decisions and effort of the concessionaire affect their conditional distribution. For example, a poorly maintained road will deliver lower service quality and sometimes part or all of it will not available. By contrast, service quality will be higher and the road will be available almost all the time if the concessionaire maintains and manages it. Because the concessionaire controls availability risk and can manage it, it should bear it. The general principle, therefore, is to allocate each endogenous risk to the party who can control and manage it.

As Hall (1998) noted, the contract's compensation mechanism allocates risks and generates incentives. For example, if the public authority fines the concessionaire when the road is not available or full of potholes, the concessionaire will spend and exert effort to maintain and keep the road available and in good state. By contrast, if nothing happens when the road is unavailable, then the concessionaire will spend less in maintenance and the undesirable outcomes will become more likely and frequent---this is moral hazard.

An example is necessarily simple, and may misleadingly suggest that it is straightforward to assess the incentives wrought by a compensation scheme and prevent moral hazard. In practice, one should never underestimate the potential of moral hazard to creep in and emerge in unexpected and sometimes very costly guises. Moral hazard is particularly important when thinking about policy risks, because many policies controlled by the public authority can affect the concessionaire's profitability. Public authorities are subject to many pressures, administrations and officials in charge of the PPP change over time and with them policy objectives shift. For example, the authority may build or expand a road that competes with the tolled PPP or may even change the rules with the express purpose of expropriating the concessionaire. Consequently, these policy risks should be borne by taxpayers, mainly to prevent the public authority's opportunism and moral hazard.

#### *3.1.3. Exogenous risks*

Many risks are controlled neither by the concessionaire nor by the public authority---they are exogenous. An exogenous risk affects the distribution of returns of the parties who bear them, but little can be done to control it. Therefore, as Hall (1998) argued, the party that bears exogenous risk sells insurance to the counterparty. Hence, the key question about an exogenous risk is who should sell insurance to whom? The general principle is that the seller of insurance should be the party best suited to bear or spread the exogenous risk.

The answer is straightforward when there are deep markets to insure against a risk: the concessionaire should buy the insurance. For example, concessionaires should bear the risk posed by an earthquake, because there is a deep market to buy insurance against them. In that case the insurance premium becomes a standard cost of doing business. Nevertheless, the answer is not straightforward when there are no markets to buy insurance against a particular exogenous risk.

Consider one of the main exogenous risks in transport PPPs funded by tolls, variability of traffic flows over the life of the contract. Demand forecasts are notoriously imprecise and, in some cases, changes in policy, which are unknown at the time of tendering, may radically affect the usage of the facility. More important, there is little that the concessionaire can do to stimulate traffic beyond keeping the road available and in good condition. Should investors bear this risk, thus selling insurance to taxpayers; or, on the contrary, should investors be shielded against demand risk, thus buying insurance from taxpayers? The answer, of course, depends on the insurance premium that investors will charge compared with the cost that taxpayers would bear to produce it, including the cost of making the bureaucracy work.

When investors are asked to bear an exogenous risk they ask for a premium whose size varies with their ability to bear and spread risk and the intensity of competition to win the concession. Economist usually point out that in perfect capital markets investors spread and price risks efficiently. Then competition for investing ensures that the exogenous risks are priced efficiently and at cost.

Nevertheless, in practice the market for PPPs is small and fragmented, and there are no specialized investment banks and analysts that follow concessions and price their securities. Therefore, exogenous risks are spread among an undetermined number of investors and absorbed by their capital. Moreover, because PPP markets are small, competition to sell insurance against exogenous PPP risks will not be intense and margins are likely to be large. Hence investor insurance against exogenous PPP risks is likely to be expensive.

Should then taxpayers sell insurance to investors and bear exogenous risks? Many argue that the government has a clear cost advantage, because it can issue debt at the risk free rate. But this alleged cost advantage is a mirage, for it ignores that taxpayers provide the capital that backs the debt and bears the risk. It is well known that any firm with a large capital will be able to issue very cheap debt; it does not mean that risk bearing is free.

It follows that that the alleged advantage of taxpayers' insurance against exogenous PPP risks cannot rest on the ability of the government of issuing risk-free debt, but on the fact that it can spread the risk among many taxpayers who are forced to bear it and cannot exploit any market power.[26] While real, this potential advantage of the government must be weighed against the administrative cost of the bureaucracy and the fact that it rests on the assumption that the government will run a competent tax policy.[27]

We are, therefore, at a bit of a cross-road, because we don't know enough to answer Hall's question categorically---who should sell insurance against exogenous risks to whom. We believe, however, that, all said, there are two reasons which make a defensible case for taxpayers to bear exogenous PPP risks and that this is cheaper---that is, the government can spread the risk of obsolescence among taxpayers at a lower cost than investors can do it in the capital market.[28]

One is simply that transport infrastructure is public, regardless of the means of procuring it. The natural benchmark is traditional provision and then it is clear that taxpayers bear exogenous

[26] Interestingly, this does not require that project returns be independent of the economy (the assumption of the Arrow-Lind theorem; see Arrow and Lind, 1970), only that some alternatives to spread risks available to the government are unavailable to the capital market (see Brainard and Dolbear, 1971).

[27] When comparing risk premiums, one should bear in mind that part of observed market spreads pay for administrative costs---intermediation uses real resources and is not free. The cost of government debt does not include the overhead costs of the government bureaucracy that intermediates between the capital markets and the funding of a particular infrastructure and therefore underestimates the cost of government-provided insurance. See Engel et al (2013).

[28] See also Makovsek and Moszoro (2018).

risks, regardless of the way the infrastructure is funded.[29] Indeed, as we show below, the PPP contract can be structured to replicate the risk distribution wrought by a public project.

The second reason is that in private infrastructure projects financed via project finance, take-or-pay contracts are routine. Effectively, a take-or-pay contract implies that all demand risks are borne by the buyer of the infrastructure service. For example, in the United States integrated freight railway companies build their own infrastructure and most of the time they commit users through long-term contracts for minimum quantities. Take-or-pay contracts are also routinely used to build pipelines and LNG liquefaction and regasification terminals.

It is telling (and a market test) that in take-or-pay contracts, private providers do not sell insurance against demand risk to the takers of the infrastructure. Indeed, the observed structure of contracting in private infrastructure is an equilibrium outcome, and it informs that infrastructure providers do not tend to specialize in bearing the exogenous risks of the projects they build and operate.

The analogue of a take-or-pay contract in public transport infrastructure is that the party that buys the service---the government--- should also bear the exogenous risks through an analogue of a take-or-pay condition. This effectively transfers the exogenous risk to the taxpayer.

One may argue that in unregulated markets private firms routinely bear large exogenous risks against which no insurance exists. Nevertheless, these risks are priced into market prices and many times consumers bear part of it by paying higher prices. In transport infrastructure, by contrast, prices are regulated at best, and they cannot play the same role as market prices, even if projects are auctioned at the outset.

#### *3.1.4 Allocating obsolescence risk*

We can now apply the general principles to obsolescence risk. It is clear that obsolescence wrought by technological and climate change is exogenous to the concessionaire and the public authority. Moreover, markets do not offer insurance against obsolescence. We conclude, therefore, that obsolescence risk in PPPs should be borne by the taxpayer. In our example this implies that after the infrastructure becomes obsolete, the government should pay $45 to the concessionaire---the present value of the net cash flows that the concessionaire would have received, had the asset not become obsolete.

Of course, in practice it will be difficult to agree that $ 45 is the amount that the concessionaire should receive. One reason is that most PPP contracts are for a fixed term (e.g. 30 years) and many are funded with tolls. Because traffic flows are random, so is “the amount that the concessionaire would have received, had the concession not become obsolete.” This amount cannot be deduced from accounting data and is highly subjective.

Also, most if not all PPP contracts assume that the concession will run its original term and do not include any rules about how to terminate it before that. Therefore, there is neither a contractual provision explaining how to terminate the contract prematurely, much less how to compensate the concessionaire in such an event.

It follows that unless the PPP contract rules how to terminate the concession before the term ends and includes specific provisions about the compensation, a protracted negotiation and dispute will follow. This dispute may delay the revamping of the infrastructure and the policy response to obsolescence. Because this is costly, it opens the door for the concessionaire to hold up the public authority. At the same time, because the outcome of disputes is uncertain, a

[29] The proof is in Engel et al. (2014a, Table 5.1).

disputed value makes the commitment to allocate obsolescence risk to tax payers suspect. In the next section we suggest a contract that allows an objective computation of the present value of the net cash flows that the concessionaire would have received, had the asset not become obsolete.

### 3.2 Achieving flexibility

#### ***3.2.1 Flexibility through a call option to buy back the PPP***

To deal with obsolescence the public authority needs discretion to terminate the PPP contract and revamp or discard the obsolete asset as soon as obsolescence hits. The problem, of course, is that discretion may foster opportunism and expropriation, and opportunism and expropriation may make it impossible to sustain trade and the PPP model. PPP contracts, therefore, generally limit discretion, for example by forcing the public authority to get the agreement of the concessionaire to modify the contract, and giving the concessionaire recourse to arbitration or court. But, of course, now the concessionaire has discretion to behave opportunistically, especially if not dealing promptly with obsolescence destroys social surplus and disrupts transportation.

All this is well known, but suppose for a moment that both the public authority and the concessionaire agree at the beginning of the concession that a specific amount, call it $C(t)$, will be the "right" compensation at time $t$; that is, $C(t)$ equals the present value of the net cash flows that the concessionaire would have received, had the asset not become obsolete. Now if at any point in time the value of the "right" compensation is precise and verifiable, then the PPP contract could give the public authority the right to terminate the contract unilaterally at any time $t$ by paying $C(t)$ to the concessionaire---that is, the contract could give the public authority a call option to terminate the contract unilaterally. We stress that so far the existence $C(t)$ is an assumption, but please bear with us for a while for the sake of building the argument.

In any case, because the concessionaire and the public authority agree that $C(t)$ is the right compensation at time $t$, the concessionaire is covered against the public authority's opportunism. At the same time, because the compensation is a verifiable quantity, and voluntarily agreed by the concessionaire, it will be harder to dispute in court. Therefore, the government has full flexibility to deal with obsolescence; indeed, in a way the government can act as if the original contract did not exist.[30] Last, note that the contract fully transfers obsolescence risk to the taxpayers[31].

Of course, so far the "result" is close to an assumption. We next describe contracts such that $C(t)$ can be calculated with verifiable accounting information at any point in time during the concession. Then we show that the rule to calculate $C(t)$ with accounting information can be fully described at the beginning of the concession, before the actual $C(t)$ is known. This rule can be used in PPPs funded with tolls, with government payments or a combination of both.

#### ***3.2.2 Implementation***

[30] It should be noted that large payments that are registered as current spending increase the current deficit. Governments tend to shy away from making such payments.

[31] One might fear that the government may refuse to buy back the concession when obsolescence hits to avoid paying the compensation. This is potentially a concern, but that is somewhat inconsistent with the premise that the government's policy objective is to adapt to obsolescence as soon as possible.

How can one price the option $C(t)$ with accounting information? It is helpful to consider first an availability contract such that the public authority pays the concessionaire $\pi$ every year for a fixed number of years $T$. If $r$ is the discount rate set in the contract, then the present value of these payments at the beginning of the concession at $t=0$ is

$$\Pi(0)=\pi\cdot\sum_{\tau=1}^{T}\frac{1}{(1+r)^{\tau}}$$
$$=\frac{\pi}{r}\cdot\left(1-\frac{1}{(1+r)^{T+1}}\right).$$

Moreover, at any point in time $t$, the remaining present value of the payments is

$$\begin{aligned}\Pi(t)&=\pi\cdot\sum_{\tau=t+1}^{T}\frac{1}{(1+r)^{\tau-t}}\\&=\frac{\pi}{r}\cdot\left(1-\frac{1}{(1+r)^{T-t}}\right).\end{aligned}\qquad(1)$$

Note that, in practice, $\Pi(t)$ can be calculated with accounting information at any time $t$, for $\pi$, $r$ and $T$ appear in the contract. Suppose now that the contract sets $C(t)=\Pi(t)$, that is, $\Pi(t)$ is the value of the call option at which the public authority can buy the contract back when obsolescence hits. Then the compensation is exactly "the present value of the net cash flow that the concessionaire would have received, had the asset not become obsolete." Hence, $C(t)=\Pi(t)$ transfers obsolescence risk to tax payers.

Note, in addition, that if the contract is allocated in a competitive auction and $I$ is the investment needed to build the infrastructure, $\Pi(0)=I$ would be the winning bid. Last, the value of the call option can be adjusted to take account of the fact that the concessionaire will spend less in operation and maintenance if the concession lasts less than $T$ years (see the example in section 4.1).

Now many transport PPPs are funded with tolls and their term is fixed. Then the sequence $(\pi(t))_{t=1}^{T}$ is a random variable which depends on the sequence of traffic flows, and so is any sequence $(\pi(t))_{t=\tau}^{T}$. Consequently, the present value of the remaining revenue at any given $t$ is a random variable with many possible realizations. So any valuation of the call option to buy back the concession would have to make a judgement call on the probability distribution of the present value of that revenue. Of course, this probability distribution cannot be determined from accounting data and is highly subjective.

As we have shown in previous work, however, a PPP can also be procured with a present-value-of-revenue (PVR) contract.[32] With a PVR contract the concession lasts until the concessionaire collects $\Pi(0)$, the present value of revenue agreed in the contract. Therefore, the term of the PPP is variable and adjusts endogenously so that the concessionaire receives the same revenue in all states of demand. For example, if the demand for the road is lower than expected, the concession lasts longer. With a PVR contract, "the present value of the net cash flow that the

[32] See Engel et al. (1997, 2001 and 2013).

concessionaire would have received, had the asset not become obsolete" can again be calculated with accounting data.

To see how, let $\text{PVR}(t)$ be the present value at time *t* of the remaining revenue that the concessionaire must receive and let $(R(\tau))_{\tau=1}^{t-1}$ be the sequence of revenues that the concessionaire received up to year $t-1$. Note that at any given time *t* the present value of the revenue that the concessionaire must still receive is

$$\text{PVR}(t) = \text{PVR}(0)\cdot(1+r)^t - \sum_{\tau=1}^{t-1}(1+r)^{t-\tau}R(\tau) \qquad (2)$$

The first term on the right hand side, $\text{PVR}(0)\cdot(1+r)^t$, is the present value of revenue that the public agency and the concessionaire agreed in the contract, brought forward to year *t*. The second term in the right-hand side is the amount already collected in tolls during the first $t-1$ years of the concession. The difference is "the present value of the net cash flow that the concessionaire would have received, had the asset not become obsolete."

Note that the present value in equation (2) can also be calculated with accounting data. Both $\text{PVR}(0)$ and *r* are written in the contract, and the sequence $(R(\tau))_{\tau=1}^{t-1}$ is in the accounts of the PPP. Therefore, the value of the call option is known at every moment during the life of the PPP. Hence, if the public authority exercises the option at time *t* when the asset becomes obsolete, taxpayers bear all the risk because the concessionaire receives the same revenue that it would have received.

As we have shown in Engel et al. (2001, 2013), the PVR contract can be implemented with a least-present-value-of-revenue (LPVR) auction. The contract is awarded to the firm that bids the lowest present value of revenue over the life of the concession. If the auction is competitive, then $\text{PVR}(0) = I$ should be the winning bid. Therefore, the return of the concessionaire will be close to normal, even if the asset becomes obsolete.

### 3.3 Possible objections

Let us now pause for a moment to revise possible objections to our solution to the problems wrought by obsolescence of transport infrastructure and, more generally, reflect about the plausibility of variable-term contracts and a buy back clause.

#### *3.3.1 Are PVR contracts feasible?*

Perhaps the most obvious objection is that under a PVR contract the term of the concession is variable, and variable term contracts are difficult to finance because banks and bondholders do not like debt that can be prepaid. Let us point out that PVR contracts have been routinely used in Chile since the mid-1990s to concession roads, tunnels and airports.

Figure 1 shows the cumulative number of transport PPPs in Chile since the PPP program was launched in 1993 with the El Melón tunnel. As can be seen in the figure, initially all PPPs were fixed term. The first LPVR contract was auctioned in 1998, but only after 2006 LPVR contracts became the norm in Chile. Note that a third type of contract ---the so-called revenue distribution mechanism or MDI--- appeared in 2002. These were five fixed-term PPPs that were renegotiated in 2002 and turned into variable-term contracts. By 2017, 29 of the 66 PPPs awarded were variable-term contracts.[33] As Figure 2 shows, by 2017 the cumulative investment in transport PPPs in Chile exceeded $12 billion. 55 percent of all investment had been made with variable-term contracts.

How are PVR contracts financed? The local financial industry, and in particular insurance companies, understands how variable-term contracts work, and participate in the financing of a PPP even during the construction phase. An important point seems to be that financiers can easily distinguish and separate prepayments that accrue because the PPP is doing better than expected from prepayments that are triggered by interest-rate swings. Typically, financiers allow the former and penalize the latter.

Note that most PVR contracts include a clause that allows the government to buy back the PPP. The concessionaire's compensation is calculated with an equation akin to (2), with an adjustment for maintenance costs.

It should not be surprising that financiers are willing to accept a variable term when they understand the logic of a PVR contract. Indeed, the first pair of present-value of revenue PPP contracts that we know about were awarded in England three decades ago.[34] In 1986 a Trafalgar House consortium won a bid to build the Queen Elizabeth II Bridge on the Thames River, a 450 meter long bridge connecting Dartford in the south and Thurrock in the north. Construction was financed with subordinated debt issued by insurance companies and term loans by banks.[35] The SPV had only nominal equity, because there was no risk involved. The bridge opened in 1991 and the PPP lasted until toll collections paid off the debt issued to finance the bridge, which occurred in March of 2002, almost ten years before the maximum concession term of 20 years. The Special Purpose Vehicle (SPV) in charge of the PPP was liquidated, the bridge reverted to public management and the government began collecting tolls, now referred to as charges.

The Second Severn Crossing on the Severn Estuary PPP, which was tendered in 1990 and opened in 1996, also used a PVR contract. The contract stipulated a term of 30 years or until the concessionaire collected £995.8 million (in July 1989 prices), whichever occurred first. Control of the crossing and the original Severn Bridge reverted to the UK government on 8 January 2018, after the project's required revenue had been collected. Responsibility for operating the bridge passed to Highways England, a public entity.

### *3.3.2 Where did risks go?*

Some commentators have pointed out that our solution to obsolescence seems to assume away risk because it requires that at any moment in time the value of the option $C(t)$ be known with precision. Indeed, it may seem at first sight that the government and the concessionaire need to know the entire trajectory of the value of the option $C(t)$ at the moment they sign the PPP contract! If such were the case, our "solution" would be little more than a theoretical curiosity with no practical value. It is not the case, however.

To see why, note that with PVR and availability contracts, $C(t)$ is a verifiable quantity that *can* be known with precision at any point in time. Verifiability stems from the fact that, as we have already said, $C(t)$ is calculated with verifiable accounting information. Precision stems from the fact that $C(t)$ is equal to the difference between the concessionaire's bid in the auction and the

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[33] 12 interurban highways, 3 urban highways, 7 airports and 2 public transport corridors.

[34] This section is based in Engel et al. (2014a, p. 67).

[35] See Hellowell (2010).

revenue that the PPP has received so far. Neither quantity is random at time *t*, nor has to be estimated.

In the case of an availability contract the sequence *C*(*t*) can be calculated at the time the PPP contract is signed, provided that the payment schedule is known and not adjusted over time in response to circumstances. When the PPP is funded with tolls *C*(*t*) is not known at the time that the government and the concessionaire sign the PPP contract, because future demand for the infrastructure is never a known quantity. Nevertheless, it is not necessary to know the value of *C*(*t*) in advance to prevent opportunism and achieve flexibility, because parties know that the quantity is verifiable at any point in time. More important, as we have seem, at any point in time *C*(*t*) is the right compensation for the concessionaire.

Our analysis does not mention probabilities (which some dismiss as unknowable anyway). Where did risk go? Once *C*(*t*) is a known quantity, dealing with obsolescence risk is just a contractual issue. The relevant question is who should bear obsolescence risk (or who should sell insurance to whom), and we have already answered that obsolescence risk should be borne by taxpayers.

Now why is *C*(*t*) a precise quantity at any given time, not an estimate, despite of the fact that the future demand for the infrastructure is never known? Note that, as we have already said, if the auction to award the PPP contract is competitive, potential concessionaires will bid close to the cost of building the infrastructure. The winning bid and the concessionaire's present value of revenues over the life of the concession, therefore, are uncorrelated with the future demand for the infrastructure. In other words, the cost of the project is the same, independent of the particular realization of demand; this is the reason why the probability distribution of future demand is not relevant to calculate *C*(*t*). A PVR contract then varies the term of the concession to ensure that the present-value of revenue received by the concessionaire is the same, regardless of the actual realization of the demand for the infrastructure. We can now see why *C*(*t*) is a precise quantity at any given *t*: the first term of the difference, $\text{PVR}(0)$, is invariant with the realization of demand; the second term, the revenues already accrues to the PPP, are independent of future realizations of the demand for the infrastructure.

### *3.3.3 Ports, airports and roads*

A relevant and valid concern is that our solution to the contracting problems wrought by obsolescence is less likely to work in airports and ports. The concessionaire can significantly affect the demand for a port terminal and for some airports by determining the quality of service. When the concessionaire can shift the demand curve by exerting effort and diligence it is, in general, a good idea to make him bear demand risk, and one simple means of doing that is to make the term of the PPP fixed. Of course, if the term of the PPP is fixed, and revenues depend on demand, *C*(*t*) is no longer a verifiable quantity that can be known with precision at any point in time and calculated with accounting information. [36]

Our solution is widely applicable to roads, tunnels and bridges, however, where demand is largely exogenous. Then availability or PVR contracts are the natural way of contracting and the call option can be easily be written into the contract. Of course, if a road is poorly maintained users may bear substantial costs and yet keep using it if they have no good alternative. Fortunately, to a large extent, objective service standards can be defined and enforced in roads,

[36] Variable-term concessions can be combined with incentives for performance in some cases. For the case of airports, see Engel et al. (2018).

tunnels, and bridges, so that quality is contractible. It is therefore possible to directly enforce quality standards and separate performance from demand risk.

### *3.3.4 Incentives and opportunism wrought by a fixed-price option*

The last concern about a buyback clause with a fixed-price option is that it may prompt the concessionaire or the government to act opportunistically. It has been suggested to us that if the concessionaire has any input into the ongoing value of the asset (either by its ability to influence demand, or its role in maintaining the asset, which affects demand or the residual life of the asset) then a fixed price call option would blunt performance incentives. Worse, any improvement to the asset that raises its value would prompt the government to opportunistically exercise the option to expropriate the value created---the authority could make money by exercising its call option and then recontracting with a new concessionaire. Hence, the more effort the concessionaire exerts, there more likely the government will expropriate.

To evaluate these concerns one should go back to basics. The first point to note is that a road, a tunnel or bridge managed by a concessionaire is a public asset that is in private hands for a limited time, and will eventually revert to the government, whether the term of the PPP contract is fixed or variable and whether there is a buyback clause in the contract or not. So the PPP contract must clearly define maintenance and conservation standards, the government must monitor compliance over the entire life of the PPP contract and, in the event that the concessionaire does not comply, enforce the contract. As said, in the case of roads, tunnels and bridges this is technically possible and, moreover, a precondition for successful PPPs.

Also, because a PPP is essentially a means of procuring public assets and services, it is unlikely that the concessionaire will go ahead and improve the asset or service before bargaining with the government. Indeed, the literature points out that blunted incentives for innovation are a problem of PPPs when the government retains control rights; a buyback clause does not create the problem.[37] For example, in 2012 changes were made to the agreement between the government and the concessionaire of the Severn Crossing PPP to compensate the concessionaire for the investments needed to install credit card handling systems. The net effect was to increase the required revenue from £995.83 million to £1,028.91 million (in 1989 prices) which marginally extended the variable term of the concession. More generally, if constant and protracted improvements to the infrastructure asset were needed to ensure timely exploitation of new market opportunities, then public ownership may be not be the adequate means of organizing service provision and production.

We are not claiming that transactions costs, opportunism, and strategic behaviour are not relevant in PPPs.[38] What we do claim, however, is that one should deal with them by procuring with PPPs only those types of infrastructure that are suited for PPPs (namely those where objective performance standards can be monitored and enforced); and by carefully crafting, monitoring and enforcing the contract. When demand is largely exogenous and objective performance standards can be defined, monitored and enforced, availability and PVR contracts are the right solution and then introducing a fixed-price buyback option is a natural means to simultaneously grant the government flexibility and protect the concessionaire from opportunism.

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[37] The classic paper is the careful analysis of Bennet and Iossa (2006).

[38] A comprehensive review of transactions costs, opportunism, renegotiations and strategic issues is in our book on PPPs, Engel et al. (2014a). The book also contains comprehensive bibliographic notes for the reader interested in the literature.

When demand responds to the efforts of the concessionaire and a fixed-term concession is appropriate, a different solution is necessary.

### 3.4 The equivalence of a PVR contract and traditional provision

We can now return to the question we made in section 2: does traditional provision deal better with obsolescence than a PPP? With traditional provision the public authority retains flexibility to deal with obsolescence. Moreover, it fully pays for the infrastructure, no matter when obsolescence hits, so that taxpayers bear obsolescence risk (though, as we have seen, the concept of obsolescence risk is not very illuminating under traditional provision). Therefore, traditional provision provides a meaningful benchmark about risk allocation and flexibility to deal with obsolescence.

Both availability and PVR contracts commit the public authority to pay an amount over the life of the concession whose present value is known when the concession begins and is written down in the contract. Because of this, the call option can be valued with accounting information at any point in the life of the contract---it is equal to the difference between the committed amount and the amount that the concessionaire has already received when the public authority exercises the option. Consequently, the public authority can retain full flexibility to buy back the concession, just as with traditional provision. Also, obsolescence risk is transferred to taxpayers, just as with traditional provision.

In addition, we have shown elsewhere that both availability and PVR contracts have the same impact on the intertemporal public budget as traditional provision.[39] For the same reason, with both availability and PVR contracts the fiscal impact of obsolescence is the same with as with traditional provision.

To see this, return to our example in section 2. Recall that the obsolete asset no longer generates \$45 in present value. Consequently, the public authority buys back the concession in \$45. Now assume that the infrastructure cost \$75. With both availability and PVR contracts the winner would have bid \$75 and would have collected \$75 − \$45 = \$30 by the time the asset became obsolete. Because the public authority pays \$45 to buy the concession back, and either pays \$30 (with an availability contract) or foregoes \$30 in toll revenue (under a PVR contract) the total cost of procuring the infrastructure is \$30 + \$45 = \$75. Now under traditional provision the public authority would have invested \$75 in present value to build the infrastructure. Therefore, it spends the same amount.

The lesson to be drawn is not that PPPs and traditional provision are the same. Of course, there are other factors or considerations that may tilt the balance one way or the other. What our analysis shows, however, is that there is no *prima facie* reason to prefer traditional provision to PPPs on the basis of flexibility and obsolescence risk allocation. Both under traditional provision and PPPs taxpayers can bear obsolescence risk and the public authority can retain flexibility to deal with obsolescence.

## 4. Inflexibility and flexibility in practice

In this section we present three examples. The first two, one in the United States and one in China, describe an inflexible and incomplete PPP contract that led to a protracted dispute which caused a net welfare loss. Both cases illustrate how a PVR contract with a clear buyback clause would have

[39] See Engel et al. (2014a, chapter 5, especially Table 5.1).

probably solved the dispute earlier, protecting the interests of the concessionaire and the public authority.

The third example describes an availability contract between a forestry company and a private company to build and maintain a 60-km road network used by heavy trucks to move lumber from the forest to the processing plant. The contract included a buyback clause triggered by a verifiable event. This case suggests how to write an availability contract with an unambiguous buyback clause.

Neither case is about obsolescence. Nevertheless, the first two illustrate why inflexible contracts are costly when circumstances change. The third case, in turn, shows how to write an availability contract with a buyback clause which can be executed if a verifiable event occurs.

### 4.1 Two case studies in inflexibility

#### 4.1.1 SR91 in Orange County

In 1995, the California Department of Transportation (Caltrans) awarded a 35-year concession for a 10-mile segment of the four-lane Riverside Freeway (also called State Route 91) between the Orange-Riverside county line and the Costa Mesa Freeway (State Route 55) to a private firm, California Private Transportation Corporation (CPTC). Motorists used the express lanes to avoid congestion in the non-tolled lanes, paying up to almost $11 for a round trip. The concessionaire was allowed to raise tolls to relieve congestion, which it did several times. By the late 1990s, 33,000 daily trips brought the express lanes to the brink of congestion at peak time, turning the concession into a financial success. At the same time and for the same reasons, users in the non-tolled public lanes were suffering congestion, and an expansion was urgently needed. Nevertheless, the contract included a non-compete clause that prevented Caltrans from increasing capacity at Riverside Freeway without CPTC's consent. Caltrans tried to elide the clause, arguing that expansions were necessary to prevent accidents, but CPTC filed a lawsuit. The settlement stated that non-compete clauses were meant to ensure the financial viability of CPTC and that they restrict Caltrans's right to adversely affect the project's traffic or revenues. Consequently, no new lanes could be built.

Protracted negotiations ensued, and eventually the Orange County Transportation Authority (OCTA) was empowered to negotiate the purchase of the tolled lanes. The value of the concession was controversial since it should have been the present value of profits from the State Route 91 Express Lanes had the franchise continued as originally planned. Although the lanes cost $130 million to build, initially the concession's value was set at $274 million in a controversial (and ultimately unsuccessful) buyout attempt by a non-profit associated with Orange County. After several years of negotiations, with frustrated commuters stuck in traffic in the meantime, the express lanes were bought in January 2003 by OCTA for $207.5 million. The California legislature gave the OCTA the authority to collect tolls and pay related financing costs and also eliminated non-compete provisions in the franchise agreement to allow for needed improvements on State Route 91.

Because this was a fixed-term PPP, demand risk was borne by the concessionaire. Therefore, this dispute was about the value of lost revenues and was unrelated to the cost of the infrastructure. Moreover, because the term was fixed, the value of lost revenues was inherently subjective. Not surprisingly, the concessionaire and OCTA disagreed. The disagreement had real economic cost: it delayed capacity expansion and prolonged costly congestion

#### *4.1.2.The Wutong Mountain Tunnel in Shenzhen, China*[40]

The 6.8 km-long Wutong Mountain Tunnel, which connects the east and west parts of Shenzhen in the Chinese province of Guangdong, opened in June 1997. It was built and is operated by a private concessionaire under a 30-year PPP contract. It can handle up to 60.000 vehicles per day and is equipped with a 12-toll booths.

From the beginning the public opposed tolling. It was argued that the tunnel monopolizes transportation between the east and west parts of Shenzhen and increases residents' living costs. Moreover, users are annoyed by frequent traffic jams at the tollbooths A proposal to cancel the toll was submitted to the municipal government of Shenzen. The municipal government studied four responses: (a) reduce the toll of the tunnel;(b) build another tunnel; (c) cancel the tollbooths and pay dividends to shareholders of the PPP in several instalments; (d) buy back the concession.

A 10-year dispute between the municipal government and the concessionaire ensued. When the concessionaire refused to lower the toll, the municipal government decided to buyback the concession, a negotiation that failed because parties could not agree on the price. The municipal government then decided to build an untolled alternative to the tunnel, which the concessionaire could not block because, contrary to Orange County, the PPP contract did not include any non-compete clause. After the alternative route opened in 2008, traffic in the tunnel fell. Then the municipal government bought back the concession at a much lower price.

In this case the origin of the dispute is a political problem confronted by the municipal government. The municipal government was intent in lowering tolls, but the contract protected the concessionaire interests. However, the municipal government went around the restriction by building an alternative to the tunnel. Here the real cost of contract inflexibility is the excess capacity that the municipal government built to lower the value of the concessionaire's revenues.

### 4.2 A forestry company procures a private road with a flexible contract

About ten years ago a forestry company in Latin America contracted the building and maintenance of a 60 km network of six roads for heavy trucks within its forests.[41] The builder/operator had to maintain the network for five years or until trucks carried a predetermined volume of lumber, whichever occurred first. The payment schedule specified a unit-price per kilometre ($P$). 24 percent of $P$ was to be paid on completion of the roads' foundations; 36 percent on completion of the road network, and the remaining 40 percent in 60 monthly instalments. Should the contract end in month $m < 60$ , there would be a final payment equal to $0.292(60 - m)P$ per kilometre.

The contract specified building standards such as width and thickness of the asphalt. In addition, the contract specifies minimum service standards that the builder/operator had to provide. At any point in time each kilometre of every road would be classified into one of three states at any point in time: "damaged" (when the damaged area was less than 30 square meters of the asphalt cover); "collapsed" (if there is more damage than in the damaged category); "optimal" (if the road is neither collapsed nor damaged).

Next, the contract defined the road as a whole to be collapsed if traffic was interrupted or if it had at least one collapsed kilometre. A damaged kilometre had to be repaired within seven days or the concessionaire would receive no monthly payment for that kilometre. A collapsed road had

[40] This subsection is based on Song et al. (2017).

[41] This section is based in Engel et al. (2014a, Box 3.1). We cannot reveal the identity of the companies.

to be repaired to “damaged” within 24 hours, or the concessionaire would receive no monthly payment for the entire road, forfeiting performance bonds.

Note that this is an availability contract with penalties for non-performance. Note, moreover, that if the contract expires after $m$ months, the total payment per kilometre of the builder/operator is equal to

$$0.6P + 0.4\frac{m}{60}P + 0.292\left(1 - \frac{m}{60}\right)P < P.$$

That is, the total compensation is less than $P$. The third term in the expression,

$$0.292\left(1 - \frac{m}{60}\right)P,$$

Is the value of the option to buy back the contract. Note that $m$ is verifiable---the end of the contract is triggered when the amount of lumber carried on the network surpasses the predetermined volume of lumber.

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**Figure 1**
**Fixed and variable term transport PPPSsin Chile**
**(cummulative number, 1993-2017)**

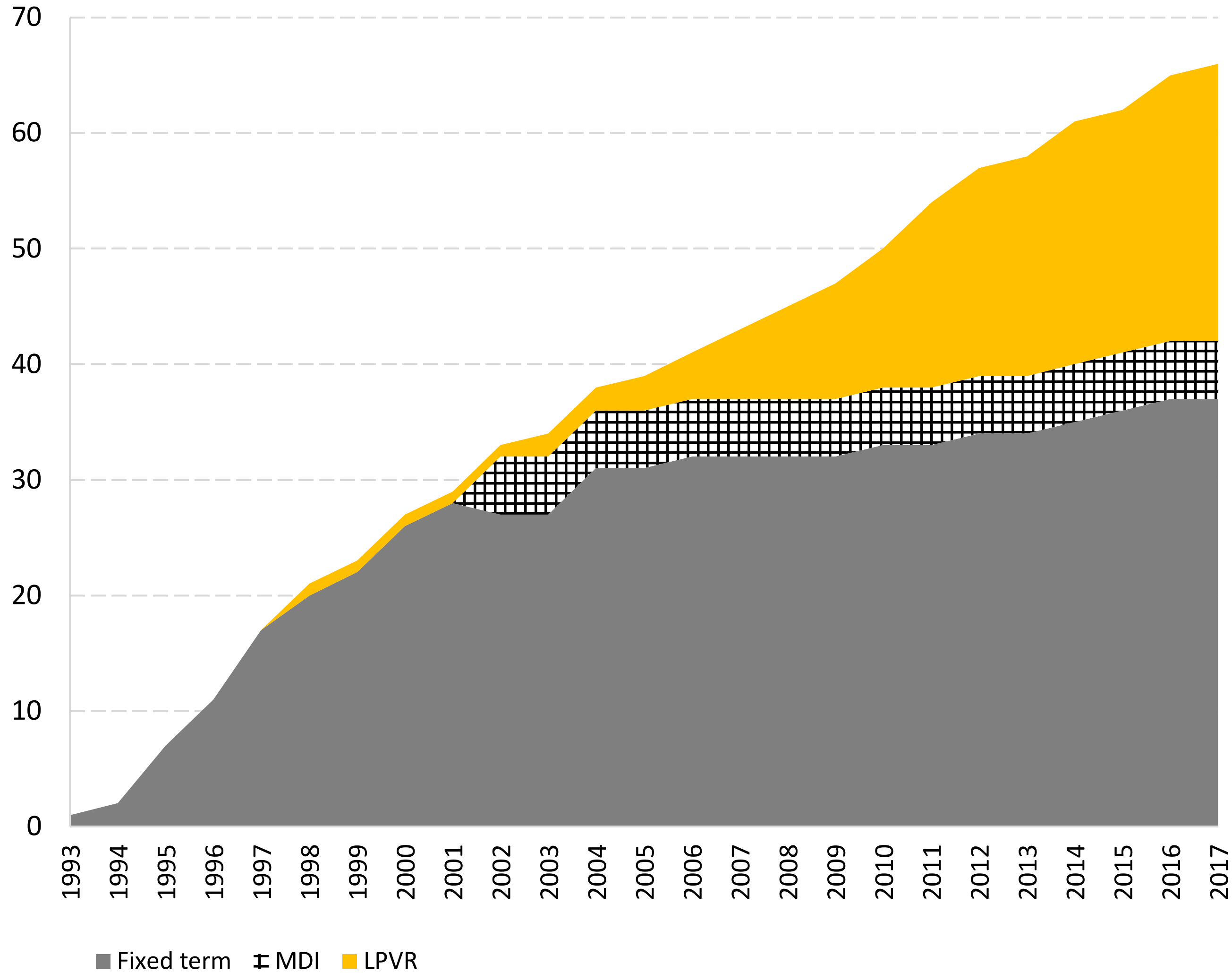


Figure 1 shows the cumulative number of transport PPPs in Chile since the PPP program was launched in 1993 with the El Melón tunnel As can be seen, initially all PPPs were fixed term. The first LPVR contract was auctioned in 1998, but LPVR contracts became the norm only after 2006. Note that a third type of contract ---the so-called revenue distribution mechanism appeared in 2002. These were five fixed-term PPPs that were renegotiated n 2002 and were turned into variable-term contracts. By 2017 29 of the 66 PPPs awarded were variable-term contracts.

**Figure 2**
**Fixed and variable term transport PPPs in Chile**
**(cummulative investment in MMUSD, 1993-2017)**

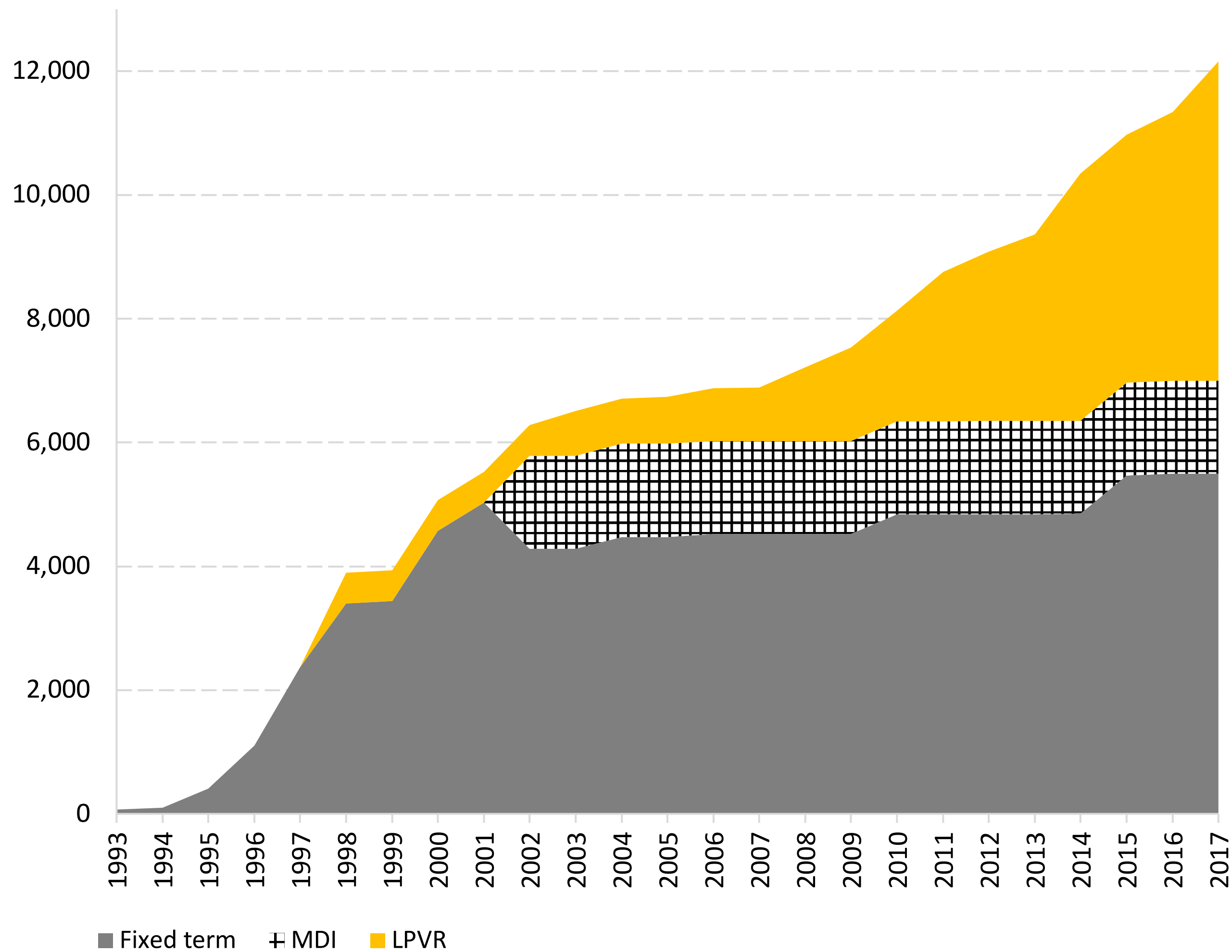


Figure 2 shows the cumulative investment in transport PPPs in Chile since the PPP program was launched in 1993 with the El Melón tunnel. As can be seen, initially all concessions were fixed term. The first LPVR contract was auctioned in 1998, but LPVR contracts became the norm only after 2006. Note that a third type of contract ---the so-called revenue distribution mechanism appeared in 2002. These were five fixed-term PPPs that were renegotiated in 2002 and turned into variable-term contracts. By 2017, 55 percent of all investment had been made with variable-term contracts.

Source: author's calculation with information provided by the Ministry of Public Works.