CHAPTER 13

REGULATORY RISK, REGULATORY UNCERTAINTY AND A TEACHING ROLE FOR REGULATORS

1 Introduction

The key feature of this paper is its focus on the potential for a teaching role for a regulator given conditions of uncertainty - a role which may in practice be welcomed as potentially mutually advantageous by the firms subject to that regulator's decisions.

In earlier work (Ryan 1999) I considered regulatory risk with particular reference to the fairness of retrospective windfall profit taxes on recently privatized nationalized industries of the kinds introduced by the UK government in 1997. After providing a very general class of more for less results and uncertainty and learning related applications of them in Section 2, in Section 3 I will review this earlier work on regulatory risk and then consider the desirability or otherwise of regulation in that wider context. In Section 4 I extend results in the earlier sections using a regulatory game as an example. The paper concludes with a numerical example to illustrate key ideas together with more general implications for regulatory policy of regulatory uncertainty as distinct from regulatory risk.

2 More for less and regulation

THEOREM 1

With M arbitrarily large and if a feasible solution exists for (I), then:

$$\text{Max } f(x) - Ms^+ - Ms^- = z \le z' = \text{Max } f(x) - h^+(s^+) - h^-(s^-)$$
$$\text{st } g(x) + s^+ - s^- = b \quad \text{(I)} \qquad \text{st } g(x) + s^+ - s^- = b \text{ (Ia)}$$
$$x, s^+, s^- \ge 0 \qquad\qquad x, s^+, s^- \ge 0$$

PROOF

Any feasible solution to (I) is a feasible solution to (Ia), and conversely. But any optimal solution to (I) with all s^+, $s^- = 0$ is a feasible but not necessarily an optimal solution to (Ia). It follows that there may exist optimal solutions to (Ia) such that $z' > z$ or $z' = z$ with $s^+ > 0$ and/or $s^- > 0$ some s^+, s^-. (Notice that if variables s_i^+, s_i^- appear in every constraint i of (I) then there is *always* a feasible solution to that system.)

Although simple, this theorem, which first appeared in Ryan 1997, is also very general. In the present context of four distinct types of application and interpretation of the variable in (I) and (Ib) will be especially useful. These are applications to framing, to learning and uncertainty, to economies of scale and scope and to regulation. These applications are considered separately in the next four subsections before being considered together in the wider context of a regulatory game in Section 4.

2.1 *A Frame Related Application*

If $U(x)$ represents an individual's preferences over commodities and x^* represents that individual's initial endowments of those commodities and if, by definition, $h^+(s^+) = h^+x^+$ and $h^-(s^-) = h^-x^-$, then (I) and (Ia) take the following form:

$$\text{Max } U(x) - Mx^+ - Mx^- = z_1 \quad z_2 = \text{Max } U(x) - h^+x^+ - h^-x^-$$
$$\text{st } g(x) + x^+ - x^- = x^* \text{ (II)} \qquad \text{st } g(x) + x^+ - x^- = x^* \text{ (IIa)}$$
$$x, x^+, x^- \ge 0 \qquad\qquad x, x^+, x^- \ge 0$$

When restricted in this way to a context of individual economic decisions Theorem 1 has an interpretation in relation to *opportunity sets.* Specifically: a choice over a relatively less constrained opportunity set via (IIa) cannot yield an optimum lower than that over a relatively more constrained opportunity set via (II). Equivalently Theorem 1 is consistent with very general regulatory or exchange related interpretations that reductions of constraints on opportunity sets may lead to strictly preferred choices of consumption plans by individuals.

In a consumer context, reductions in h_i^+, h_i^- from preemptively large levels in (II) to nonpreemptively large levels in (IIa), leading to changes in optimally chosen mixes of consumption commodities, might be associated with regulatory (tax or subsidy) interpretations as well with processes of gift or exchange.

2.2 *Uncertainty and Learning Related Applications*

The systems (II),(IIa) can be extended again to cases in which an agent gains otherwise unobtainable information about a new commodity i=0 as follows:

$$\text{Max } U(x,x_0) = z_1 \qquad z_2 = \text{Max } U(x,x_0)$$
$$-h'^+ x^+ - h'^- x^- + h_0'^- x_0^- \qquad -h^+ x^+ - h^- x^- - h_0^- x_0^-$$
$$\text{st } g(x,x_0)+x^+-x^-=x^* \text{ (III)} \quad \text{st } g(x,x_0)+x^+-x^-=x^* \text{ (IIIa)}$$
$$x_0-x_0^-=0 \qquad\qquad x_0-x_0^-=0$$
$$x, x^+, x^-, x_0, x_0^- \geq 0 \qquad x, x^+, x^-, x_0, x_0^- \geq 0$$

If $h_i'^+ \geq h_i^+$ and $h_i'^- \geq h_i^-$ all $i \neq 0$ and $h_0'^- = h_0^- = M$ arbitrarily large then, by a straight-forward variant of Theorem 1, an optimal solution to (III) cannot be greater than an optimal solution to (IIIa) and exchange and regulatorily induced switches of chosen commodities $i=1,2....I$ may follow in a manner wholly analogous to that considered in Section 2.1. But now, in addition to switches between existing commodities using existing technologies there is also the possibility of a solution with $x_0^- > 0$ at an optimum in (IIIa). Such a solution will in general correspond to a *switching* response, involving a partial or complete switch from an optimal "old commodity/old technology" solution with $x_0=0$ via (III), to a relatively preferred optimal "new commodity/new technology" solution with $x_0>0$ via (IIIa).

In this way, as well as including frame related switching interpretations (III) and (IIIa) comprehend two distinct types of learning and innovation related cases. First are cases in which x_0 determines x_0^-. In that way innovation may be initiated internally via x_0 by the individual solving (III) and (IIIa) as if in order to be communicated externally via x_0^-. Secondly, there are cases in which x_0^- determines x_0. In that way innovation may be initiated externally and then communicated to the individual solving (III) and (IIIa). In either case new information x_0, x_0^- will be conveyed via (IIIa) as if in consequence of relative reductions in the magnitudes of framing parameters from $h_0'^-$ to $h_0^- < h_0'^-$. Furthermore, in general that new information will lead to a choice of optimal x_j via (IIIa) *different from* those chosen via an optimal solution to (III).

Here are teaching and learning related
$$\text{Max } U=$$
$$U_1(y_{11},y_{12},..y_{10}) - h_i'^{12} x_i^{12} - h_i'^{21} x_i^{21} + h_{10}'^- x_{10}^- \qquad +$$
$$\text{st } y_{1j} \leq g_{1j}(x_{1ij},..x_{10j})$$
$$\Sigma x_{1ij} + x_i^{12} - x_i^{21} = x_{1i}^*$$
$$\Sigma x_{10j} + x_0^{12} - x_0^{21} = x_{10}$$
$$x_{10} - x_{10}^- = 0$$

interpretations of (III) and (IIIa) stemming from elements of relatively internal and external information x_0, x_0^-, which may not just be previously unknown to, but previously unanticipated by, individuals interacting respectively internally and externally with reference to the quantities $h_0'^-$, $h_0' x_0^-$ framing those systems. These are key ideas, which I will link to issues of regulatory uncertainty (as distinct from regulatory risk) in Section 4.

2.3 *An Economies of Scale and Scope Related Application*

Programme (IV) below develops ideas in Section 2.1 and Section 2.2 by simultaneously incorporating opportunities for exchange of resources $i=1,..I$ between two individuals (or co-operating groups of individuals) "r" and "s" via x_i^{rs}, x_i^{sr} and for innovation and learning opportunities of types considered in Section 2.2 via a commodity $i=0$.

DEFINITION 1 *(Economies of scope)*

Economies of scope arise in a multi region economy when hitherto unavailable (or untaken) shipping opportunities become available via reductions in one or more relevant shipping costs.

In (IV) there are two types of potential for economies of scope, namely that arising from linkages via x_i^{rs}, x_i^{sr} between individuals r and s, and that arising from externally induced quantities x_{i0}^-. Consider x_i^{rs}, x_i^{sr} first. If $h_i'^{rs}, h_i'^{sr}$ are sufficiently large then, other things equal, the overall optimal value U^* in (IV) will be such that $x_i^{rs} = x_i'^{sr} = 0$ all i,r,s. But, if one or more of $h_i'^{rs}, h_i'^{sr}$ are sufficiently reduced, correspondingly optimal values of (IV) will be such that $U^{**} \geq U^*$ by a variant of Theorem 1, so potentially yielding *exchange* related economies of scope.

$$U_1(y_{21},y_{22},..x_{20}) - h_i'^{12} x_i^{12} - h_i'^{21} x_i^{21} + h_{20}'^- x_{20}^-$$

$$\text{(IV)}$$

$$y_{2j} \leq g_{2j}(x_{1ij}, x_{20j})$$
$$\Sigma x_{2ii} + x_i^{21} - x_i^{12} = x_{2i}^* \quad i \neq 0$$
$$\Sigma x_{20j} + x_0^{21} - x_0^{12} = x_{20}$$
$$x_{20} - x_{20}^- = 0$$

All variable nonnegative

Next consider x_{i0}^-. With h_{r0}^-, h_{s0}^- sufficiently large the overall optimum U* in (IV) will be such that $x_{r0}^-=0$. But, if one or more of h_{r0}^-, h_{s0}^- are sufficiently reduced, the optimum U** in (IV) may be such that U**≥U*, again by a variant of Theorem 1, and so yield *innovation* related economies of scope.

[Notice that the constraints of (IV) are such that innovation induced economies of scope will generally have production related implications (via the quantities x_{r0} in the relations $g_{2i}(x_{11},x_{12},..x_{20})$). And/or, if potential communication costs $h_i'^{12}$ are sufficiently low, relatively externally induced innovations x_{20} relative to one individual may be transmitted at an optimum to another via relations x_0^{rs}.]

DEFINITION 2 *(Economies of scale)*

Economies of scale are defined as arising in a multiregion economy when it is possible to increase the total amount produced in at least one region and for at least one market so that average production costs are reduced, even when (increased) economies of scope are not available.

To see how economies of scale may arise, consider a development of (IV) with U interpreted as profit contributions (revenue net of variable production costs) to two spatially distinct production plants. Assume that (IV) is also augmented by preemptively specified targets $y_{ri}^*, x_{ri}^*, x_i^{sr*}, x_i^{rs*}$ and parameters associated with potential deviations t_{ri}^+, t_{ri}^- (resp $\tau_{ri}^+, \tau_{ri}^-, c_i^{sr}$) from them as in (V).

By a variant of Theorem 1, economies of scale may arise if, via sufficient reductions in the penalties t_{ri}^+, τ_{rij}^+, demand and supply for commodity i optimally increases other things equal (respectively via $y_{ri}^+>0$ and $x_{rij}^+>0$) in such a way as to reduce overall production cost. [Sufficient conditions here are for U( ) to be interpreted as referring to net revenue contributions and for marginal net revenue to be constant at the relevant margin.)]

$$\text{Max}\quad U=\Sigma(U_r(y_{rj},y_{r0})- h_i'^{rs}x_i^{rs}-h_i'^{sr}x_i^{sr} + h_{r0}'^- x_{r0}$$
$$- \Sigma(t_{rj}^+y_{rj}^+ + t_{rj}^-y_{rj}^- + \tau_{rij}^+x_{rij}^+ +\tau_{rij}^+x_{rij}^+)$$
$$- \Sigma(c_i^{rs+}x_i^{rs+} + c_i^{rs-}x_i^{rs-} + c_i^{sr+}x_i^{sr+} + c_i^{sr-}x_i^{sr-})$$
$$\text{st}\qquad y_{rj}\leq g_{ri}(x_{ri},x_{r0})$$
$$y_{rj} + y_{rj}^+ - y_{rj}^- = y_{rj}^*$$
$$\Sigma x_{rij}+ x_i^{rs} - x_i^{sr} = x_{ri}^* \quad i=1,2...I \quad (V)$$
$$\Sigma x_{r0j}+ x_0^{rs} - x_0^{sr} =x_{r0}$$
$$x_{rij} + x_{rij}^+ - x_{rij}^- = x_{rij}^*$$
$$x_i^{rs} + x_i^{rs+} - x_i^{rs-} = x_i^{rs*}$$
$$x_i^{sr} + x_i^{sr+} - x_i^{sr-} = x_i^{sr*}$$
$$x_{r0} - x_{r0}^- =0$$
$$\text{All variables nonnegative}$$

2.4 Regulation and Deregulation Related Applications

The quantities $t_{ri}^+, t_{ri}^-, \tau_{rij}^+, \tau_{rij}^+$ in (V) have potential interpretations as regulatory taxes (for demand and/or production beyond target levels) or subsidies (for demand and/or production short of target levels). With this perspective (V) straightforwardly yields regulatory interpretations. For example (V) potentially yields interpretations according to which, other things equal, a reduction in tax or an increase in subsidy for a consumption or production related commodity will respectively increase consumption or production of that commodity. In general such direct effects leading to increases in demand/and or of supply will also have indirect implications for levels of "exports" and "imports" via the first constraints of (V).

Alternatively, "exports" and/or "imports" may be regulated directly via corresponding changes in the magnitude of the "export" and "import" related parameters $c_i^{rs+}, c_i^{rs-}, c_i^{sr+}, c_i^{sr-}$. That is, other things equal, "exports" will increase if c_i^{rs+}, are increased (or c_i^{rs-} are reduced) and "imports" will increase if c_i^{sr+}, are increased (or c_i^{sr-} are reduced). That leads in turn to issues concerning the regulation of industrial and market monopoly, oligopoly or competition in general, and concerning the *contestability* or otherwise of spatially separated markets in particular. Developments of these kinds are taken up in the next Section.

3 Economies of Scale and Scope, Contestability and Regulation

As I noted in Ryan 1999 the contestability idea was first developed in Baumol, Panzer and Willig, 1982, where a contestable market is defined as having the following properties:

First, the potential entrants can, without restriction, serve the same market demands and use the same productive techniques as those available to the incumbent firms... Second, the potential entrants evaluate the profitability of entry at the incumbents' pre-entry prices. (Baumol et al (1982) p.5)

These definitions, and particularly the free exit aspect of them, have always been contentious. An especially strong critic is Shepherd (1984, 1995) who maintains that Baumol et al's two properties are inconsistent, since, if entry was reversible and the entrant could establish themselves with no price response, there could be no contest so that the second kind of calculation would be redundant. Another and more recent critic is

Cairns (1996) who maintains that both contestability and risk can be modelled appropriately but not simultaneously. Briefly, Cairns introduces asymmetric information related uncertainty such that exit is not "free" since potentially entering firms may then realize unanticipated losses relative to incumbents.

It is a remarkable feature of Baumol et al's definition of contestability, as well as these criticisms of it, that that definition and those criticisms make no distinction between contestability where an enterprise is producing inside a market and contestability where an enterprise is simply importing into a market. In the first case contest-ability involves installing or removing elements of production capacity, whereas in the latter it does not. Nor do these definitions and developments, e.g. by Cairns, acknowledge that, if risks of future states were known, then those risks could be anticipated – at least in part - in current decisions. Indeed, if foresight was perfect and capital markets were also perfect, such contingent risks would be fully insurable.

These remarks indicate the key ideas which I developed in Ryan 1999. In that paper I gave new definitions of *market contestability*, which has reference to the regulation of conditions of potential entry via imports, as distinct from *industrial contest-ability,* which has reference to the regulation of conditions of potential entry via additional locally producing capacity. I also developed a multi-period goal programming formulation of a state preference model. I then used that model and these new definitions of contestability with a scale and scope related variant of Theorem 1 to show how contingent profits and losses, which may stem from regulation related windfall profit taxes, would in effect be fully anticipated and in that sense *not* unfair. For details of these analyses and results the reader is referred to Ryan 1999. But the main import of that work can be understood using a state contingent regulation variant of (V) in Section 2 in which there may be k=1,2….K distinct types of regulatory regime and in which the enterprise is assumed to adopt a maximin objective as in (VI).

$$\text{Max } \rho$$

$\theta_k \quad \text{st} \ \Sigma(U_{rk}(y_{rj},y_{r0})-h_{ik}'^{rs}x_i^{rs}-h_{ik}'^{sr}x_i^{sr}+h_{r0k}'^{-}x_{r0}^{-}$

$\qquad -\Sigma(t_{rjk}^{+}y_{rj}^{+}+t_{rjk}^{-}y_{rj}^{-}+\tau_{rijk}^{+}x_{ri}^{+} + \tau_{rijk}^{+}x_{ri}^{+})$

$\qquad -\Sigma(c_i^{rs+}x_i^{rs+} + c_i^{rs-}x_i^{rs-} + c_i^{sr+}x_i^{sr+} + c_i^{sr-}x_i^{sr-}) \geq \rho$

$\varphi_{rj} \qquad \text{st} \quad y_{rj} \leq g_{ri}(x_{rij},x_{r0}) \qquad\qquad \text{(VI)}$

$\psi_{rj} \qquad\qquad y_{rj} + y_{rj}^{+} - y_{rj}^{-} = y_{rj}*$

$\lambda_{ri} \qquad\qquad \Sigma x_{rij} + x_i^{rs} - x_i^{sr} = x_{ri}*.. \ i=1,2…I$

$\lambda_{r0} \qquad\qquad \Sigma x_{r0j} + x_0^{rs} - x_0^{sr} = x_{r0}$

$\xi_{rij} \qquad\qquad x_{rij} + x_{rij}^{+} - x_{rij}^{-} = x_{rij}**$

$\omega_i^{rs} \qquad\qquad x_i^{rs} + x_i^{rs+} - x_i^{rs-} = x_i^{rs}*$

$\omega_i^{sr} \qquad\qquad x_i^{sr} + x_i^{sr+} - x_i^{sr-} = x_i^{sr}*$

$\eta \qquad\qquad\qquad x_{r0} - x_{r0}^{-} = 0$

All variables nonnegative

As well as industrial and market contestability related interpretations, (VI) now also comprehends k=1,2…K distinct sets of contingent regulatory conditions. In that connection the regulatory tax parameters $t_{rjk}^{+}, t_{rjk}^{-}, \tau_{rijk}^{+}, \tau_{rijk}^{+}$ and "export" and "import" parameters $c_i^{rs+}, c_i^{rs-}, c_i^{sr+}, c_i^{sr-}$ take on correspondingly state contingent interpretations at an optimum. The meaning of these will be clearer with the aid of the Kuhn Tucker conditions associated with (VI). These are considered together with related developments in relation to regulatory risk and regulatory uncertainty in the next section.

4. Regulation games

The risk related analysis in Ryan 1999 with its associated distinctions between industrial contestability and market contestability arguably provides a significant improvement on analyses implicitly assuming conditions of certainty as well as of complete information. Nevertheless that earlier work, by relying on the assumption of a state preference framework, implicitly assumed that there was no uncertainty and, a fortiori, no *regulatory* uncertainty. In that respect it provided an approx-imation, at best, to real world cases, in which regulatory uncertainty as well as regul-atory risk are typically important.

In this section I consider regulation related uncertainty, as distinct from regulation related risk within the wider context of regulation related games stemming from an interpretation of (VI) and the Kuhn Tucker conditions associated with it.

Assuming that U( ) are concave and associating the indicated variables with its constraints (VI) generates Kuhn Tucker conditions as in (VI)':

$\rho \geq 0 \qquad\qquad\qquad \Sigma\theta_k \geq 1$

$y_{rj} \qquad\qquad \varphi_{rj} + \psi_{ri} \geq \Sigma\theta_k U_{rk}'(y_{rij},y_{r0})$

$y_{rj}^{+} y_{ri}^{-} \qquad\qquad - t_{rik}^{+} \leq \psi_{ri} \leq t_{rik}^{-}$

$x_{rij} \qquad\qquad \lambda_{ri} + \xi_{ri} \geq \Sigma\varphi_{ri}g_{ri}(x_{ri},x_{r0}) \quad i=1,2,.I$

$x_{ro} \qquad\qquad \lambda_{r0} + \xi_{r0} + \eta \geq \Sigma\varphi_{ri}g_{ri}(x_{rij},x_{r0}) \quad i=0$

(VI)'

$x_{ri}^{+} x_{ri}^{-} \qquad\qquad - \tau_{rik}^{+} \leq \xi_{ri} \leq \tau_{rik}^{-} \qquad\qquad i=0,1,….I$

$x_i^{rs} \qquad\qquad \psi_{ri} - \psi_{si} \leq \omega_i^{rs}$

$x_i^{rs+} x_i^{rs-} \qquad\qquad - c_i^{rs+} \leq \omega_i^{rs} \leq c_i^{rs+-}$

$x_i^{sr} \qquad\qquad \psi_{si} - \psi_{ri} \leq \omega_i^{sr}$

$x_i^{sr+} x_i^{sr-} \qquad\qquad - c_i^{sr+} \leq \omega_i^{sr} \leq c_i^{sr+-}$

$x_{r0}^{-} \qquad\qquad\qquad \eta \leq h_{r0k}'$

In (VI)', as long as $\rho>0$ at an optimum (i.e. as long as the contingent return in (VI) is positive for at least one state k), the first condition will hold as an equality. This is consistent with interpretation of θ_k as *implicitly* corresponding to regulatory risk related probabilities for an optimally determined set of contingent regulatory states $K_1 \leq K$. Notice that the complementary collection $K-K_1$ of contingent regulatory strategies is thereby implicitly assigned a probability of zero at such an optimum. Before considering this further with the context of regulatory uncertainty and a regulation game, I give brief interpretations of the remaining constraints of (VI)' as follows:

From the second constraints commodity j will optimally be supplied, if at all, then to the point where the expected marginal return, e.g. profit contribution, equals marginal supply cost φ_{rj} *net* of a demand based tax or subsidy ψ_{ri}. [From the third constraints the magnitude latter quantity depends depending on whether demand falls short of, or exceeds, the demand goal y_{rj}^*.]

Similarly, from the fourth through sixth constraints, inputs to production will be employed at an optimum, if at all, then only to the point where the marginal factor cost λ_{ri} net of any relevant factor related tax or subsidy ξ_{ri} equals the marginal revenue product of that factor. [The fifth constraint refers, via η, to a factor which would only become known if h_{r0k}' are sufficiently large, i.e. if the opportunity cost of ignorance is insufficiently large. (From the last constraint of (VI)' and complementary slackness, if $\eta < h_{r0k}'$ then $x_{r0}^- = x_{r0} = 0$.)]

The remaining four constraints relate to transfers between individuals/regions. They are consistent with the optimizing rule: transfer commodities between individuals/regions r, s, if at all, then to the point where the marginal evaluation at r equals the marginal evaluation at s plus the potentially regulated marginal transfer cost ω_i^{rs}.

Now reconsider (VI) and (VI)' from the perspective of a regulation game. In that context, as has already been noted, θ_k potentially have implicit interpretations as regulatory risk related probabilities for an optimally determined set of contingent regulatory states $K_1 \leq K$, so that the complementary collection of states $K_1..K$ are implicitly assigned probabilities of zero. In this way the decisionmaker implicitly distinguishes four distinct types of regulatory contingency:

i. Known regulatory contingencies k, implicitly assigned *nonzero* probabilities of occurrence;

ii. Known regulatory contingencies k, implicitly assigned *zero* probabilities of occurrence.

iii. Unknown regulatory contingencies, implicitly assigned *nonzero* probabilities of occurrence.

iv. Unknown regulatory contingencies, implicitly assigned *zero* probabilities of occurrence.

	Positive Prob*	Zero Prob
State Known	i)	ii)
State Unknown	iii)	iv)

TABLE 1

*NB In every case exact probabilities may be unknown

These four possibilities, which are summarized in Table 1, follow directly from the first constraints of (VI) and complementary slackness viz:

$$\theta_k \geq 0 \Leftrightarrow \Sigma(U_{rk}(y_{rj},y_{r0})-h_{ik}'^{rs}x_i^{rs}-h_{ik}'^{sr}x_i^{sr}+h_{r0k}'^-x_{r0}^- - \Sigma(t_{rjk}^+y_{rj}^+ + t_{rjk}^-y_{rj}^- + \tau_{rijk}^+x_{ri}^+ + \tau_{rijk}^+x_{ri}^+) \geq \rho$$

By complementary slackness with reference to i) and iii): if in the first constraints of (VI)' the kth holds as an *equality* that is consistent with the imputation of nonzero probabilities $\theta_k>0$ respectively to known and unknown contingencies k. And, with reference to ii) and iv) if in the first constraints of (VI)' the kth holds as an *inequality* that is consistent with the imputation of zero probabilities $\theta_k>0$ respectively to known and unknown contingencies k.

It is particularly significant here that, since a measure of risk θ_k is at best *implicit* - i.e. not explicitly specified, even as a prior, either by the decisionmaker in (VI) or by a regulator through (VI)' - *all* of these four classes of contingently optimal states are arguably uncertain. In more detail:

ia): states under i) are uncertain in the sense that, even though the nature of the future contingent outcomes may be completely known, (and in that sense certainly known), and even though such states are assigned a positive probability of occurrence, the magnitude of that probability is unknown. [In general not only may the magnitude of the relevant probability within a given range of relatively risky alternatives be unknown but, given the possibility that cases of types i) and iv) may coexist, in general the overall *range* of the relevant probability distribution will also be unknown.]

iia): states under ii) are uncertain in the sense that, even though the nature of the future contingent outcomes may be completely known (and in that sense certainly known), such states are nevertheless assigned a probability of occurrence of zero.

iiia): states under iii) although arguably less uncertain than states in iv) are nevertheless uncertain with reference to the definition of the contingent outcomes.

iva): states under iv) appear uncertain a fortiori because such states are unspecified both with reference to the definition of the contingent outcomes and with reference to the contingent probabilities.

In this way an optimal solution to (VI) *implicitly* imputes *four different kinds* of probabilities θ_k to potentially forthcoming regulatory states. Importantly a regulator might take a variety of correspondingly distinct kinds of regulatory actions, not only to make previously unknown contingencies known, but to make already known contingencies *better* known. One summary form in which such action may be taken is by providing more - or different - information concerning contingent penalties or rewards, so modifying some or all of the contestability related production or exchange related parameters of the first constraints in (VI). In that way a regulator may induce changes in decisions by regulated individuals or industries in a manner analogous to the result in Theorem 1.

Another way in which a regulator may seek actively to influence a decisionmaker's choice of output(s) is by explicitly assigning positive probabilities to some or all potentially forthcoming contingencies k=1,2….K. In that way additional information $\theta_k = \theta_k^* > 0$ in (VI)' may in effect *force* the corresponding inequalities in (VI) to become equalities. To clarify the regulatory role which might be played by such additional information I consider some special cases in the next section.

5 Regulatory uncertainty and learning: related examples

Consider a class of special cases for which (VI) is interpreted as a firm vs regulator game in which U( ) equate to profit contributions $\Sigma\pi_{rjk}y_{rjk} + \Sigma\pi_{r0k}y_{r0}$ contingent on outcomes k. In that case (VI) takes the form shown in (VII):

$$\text{Max} \quad \rho$$

$$\theta_k \quad \text{st } \Sigma\pi_{rjk}y_{rjk} + \Sigma\pi_{r0k}y_{r0} - h_{ik}'^{rs}x_i^{rs} - h_{ik}'^{sr}x_i^{sr} + h_{r0k}'^{r}x_{r0}^-$$
$$-\Sigma(t_{rjk}^+ y_{rj}^+ + t_{rjk}^- y_{rj}^- + \tau_{rijk}^+ x_{ri}^+ + \tau_{rijk}^+ x_{ri}^+)$$
$$-\Sigma(c_i^{rs+}x_i^{rs+} + c_i^{rs-}x_i^{rs-} + c_i^{sr+}x_i^{sr+} + c_i^{sr-}x_i^{sr-})$$

$$\geq \rho$$

$$\varphi_{rj} \qquad \text{st} \quad y_{rj} \leq g_{ri}(x_{rij}, x_{r0})$$
$$\psi_{rj} \qquad y_{rj} + y_{rj}^+ - y_{rj}^- = y_{rj}^*$$
$$\lambda_{ri} \qquad \Sigma x_{rij} + x_i^{rs} - x_i^{sr} = x_{ri}^*$$
$$\qquad\qquad\qquad\qquad i = 1,2\ldots I \quad \text{(VII)}$$
$$\lambda_{r0} \qquad \Sigma x_{r0j} + x_0^{rs} - x_0^{sr} = x_{r0}$$
$$\xi_{rij} \qquad x_{rij} + x_{rij}^+ - x_{rij}^- = x_{rij}^{**}$$
$$\omega_i^{rs} \qquad x_i^{rs} + x_i^{rs+} - x_i^{rs-} = x_i^{rs*}$$
$$\omega_i^{sr} \qquad x_i^{sr} + x_i^{sr+} - x_i^{sr-} = x_i^{sr*}$$
$$\eta \qquad\qquad x_{r0} - x_{r0}^- = 0$$

All variables nonnegative

For example, in (VII) π_{rjk} may be weather and regulation contingent payoffs to a firm's products j, where x_{ri}^* are the inputs of type i available in region r and x_{rij}^{**}, y_{rj}^* are relevant input technology and output production targets. In that context x_i^{rs*} x_i^{rs*} become relevant import and export targets such that deviations from targets may be varied to correspond to industrial and/or to market contestability mechanisms. Depending on the forthcomiing contingency, different types of production technique may be favoured or disfavoured via changes in local inputs to production x_{rij} or outputs y_{rj} (so changing industrial contestability conditions), and/or by changing import or export taxes or subsidies (so modifying market contestability conditions).

The kinds of cases modelled by (VII) were considered in a state contingent framework in Ryan 1999 with reference to work on contestability by Baumol et al 1982, 1986, Shepherd 1984, 1995 and Cairns 1996, as well as by Eaton and Wooders 1985, Dafermos and Nagurney 1987 and Norman and Thisse 1997. By contrast with the focus on relations between a regulator and a regulated industry under conditions of risk in that earlier paper, here attention is focused primarily on the relation between an industry and its regulator under conditions of regulatory *uncertainty*. Such conditions, although in general coexisting with conditions of regulatory risk, are distinct from them in two related ways both of which have been emphasized in the previous sections. First is the subjective nature of probabilities which a regulated firm may associate with regulatory contingencies, even when those contingent states themselves are known. Secondly, in general there will be uncertainty as to the nature of potentially forthcoming states per se - i.e. uncertainty as to the *range* of the relevant sample space.

In the latter context a direct way in which a regulator may change the range of potential outcomes is by changing market contestability conditions (e.g. by lowering taxes on potential imports from other regions). A more subtle way in which a regulator may change the range of potential outcomes, and thence influence the decisions of regulated firms, is by lowering the cost of innovation h_{r0k}^{r} in (VII). [Other things equal, a sufficient reduction in the marginal cost of introducing innovation, h_{r0k}^{r}, will increase the level of innovation x_{r0}^{-} and thence the value of x_{r0} in (VII).]

To illustrate these possibilities consider a simple two product two state numerical example in which a firm in region r has $x_{ir}^{*}=100$ units of a single type of capacity i, which may be used to produce two distinct types of output j=0,1 - the second according to a known process and the first by using an innovatory process. Assume that there are two potentially forthcoming states k=1,2 and that the contingent payoffs are as in Table 2. Assume that the target level of output 1 is 50, that penalties associated with any deviation from this target will be 25 per unit if state 1 occurs and 10 per unit if state 2 occurs and, for simplicity, that there are no output targets for output y_{r1}. Assume finally that the production relations for products y_{ro} and y_{r1} are as indicated in (VIIa)* and that the objective of the firm is to maximize the minimum expected return to its capacity.

	Output 1	Innovatory Output
State 1	5	4
State 2	3	6
	TABLE 2	

With data as in Table 2 the optimal plan for the firm could be found as an optimal solution to a specialization of (VII) via (VIIa)*:

$$\text{Max} \quad \rho$$

θ_1	st	$5y_{r1} + 4y_{r0} - \Sigma(h_{i1}^{sr}x_1^{sr} + h_{i1}^{rs}x_1^{rs}) - h_{r0}'x_{r0}' - 25(x_{r11}^{+} - x_{r11}^{-}) \geq \rho$
θ_2		$3y_{r1} + 2y_{r0} - \Sigma(h_{i2}^{rs}x_i^{1s} + h_{ri2}^{rs}x_1^{rs}) - h_{r0}'x_{r0}' - 10(x_{r12}^{+} - x_{r12}^{-}) \geq \rho$
φ_{r1}		$y_{r1} \leq 5x_{r11} + 1.5x_{r0}$
φ_{r2}		$y_{r0} \leq 2.5x_{r0}$
λ_{r1}		$x_{r11} + x_1^{sr} - x_1^{rs} = 50$ $\quad\quad$ (VIIa)*
ξ		$x_{r11} + x_{r11}^{+} - x_{r11}^{-} = 100$
η		$x_{r0} = x_{r0}'$
δ		$x_{r0}' \leq x_{r0}'^{*} = 80$
		All variables nonnegative

First consider solutions and policy alternatives in which by assumption both interregional shipment costs h_{ik}^{sr}, h_{ik}^{rs} and innovation costs h_{r0}' are initially prohibitively high. Under these conditions the optimal solution to (VIIa)* is such that $x_{r11}=50$, $x_{r11}^{+}=50$, $y_{r1}=250$, $\rho=\min[0,250]=0$. This outcome implies an *industrial monopoly* for this firm since entry from outside region r is in effect blockaded by prohibitively high entry costs/tariffs h_{i1}^{sr}. Clearly one policy alternative would be to introduce market contestability by reducing h_{ik}^{sr} accordingly. For example, with $h_{11}^{sr}=10$, $h_{12}^{sr}=5$ and the other data remaining unchanged, the optimal solution to (VIIa)* becomes $x_{r11}=100$, $x_1^{sr}=50$, $x_{r11}^{+}=0$, $y_{r1}=500$, $\rho=\min[2000,1250]=1250$.

With reference to Table 1 the first of these optima is consistent with the selection of outcomes i) and ii) via the imputation of a prior probabilities $\{\theta_1=1 \ \theta_2=0\}$ to states k=1,2. Again with reference to Table 1 the second of these optima is consistent with the selection of outcomes i) and ii), but in this case via the imputation of prior probabilities $\{\theta_1=0, \theta_2=1\}$ to states k=2. That is: a change in one of the parameters h_{i1}^{sr}, h_{i1}^{rs}, which in turn determine market contestability conditions, has caused a *switch* in predicted outcomes and, with it, a switch in subjective probabilities implicitly imputed to forthcoming regulatory states from $\{\theta_1=1, \theta_2=0\}$ to $\{\theta_1=0, \theta_2=1\}$.

A second class of special cases is one in which h_{r0}' is reduced from the preemptively high level considered in the previous case to $h_{r0}'=5$. With interregional shipment costs h_{ik}^{sr}, h_{ik}^{rs} preemptively high and $h_{r0}'=5$ and the remaining data as before, the optimum to (VIIa)* is now such that $x_{r0}=x_{r0}'=80$, $x_{r11}=50$, $x_{r11}^{+}=50$, $y_{r0}=200$, $y_{r1}=250$, $\rho=\min[400,250]=250$. This is consistent with $\{\theta_1=0, \theta_2=1\}$ and contrasts with the preemptive shipment case in the absence of innovations considered above and conditions as if $\{\theta_1=1, \theta_2=0\}$. [Notice that this switch is entirely due to the reduction in the unit cost of innovation.]

Finally consider cases in which there may both be innovation, via $h_{r0}'=5$, and improved

142

contestability via nonpreemptive magnitudes for $h_{11}^{sr}=10$, $h_{12}^{rs}=5$. With the remaining data as before, the optimum to (VIIa)* is now such that $x_{r0}=x_{r0}'=80$, $x_{r11}=100$, $x_{r11}^{+}=0$, $y_{r0}=200$, $y_{r1}=250$, $\rho=\min[1550,900]=900$. This is again consistent with $\{\theta_1=0, \theta_2=1\}$

In each of these cases there is uncertainty as to the range of potentially forthcoming states (i.e. as to the probability with which innovation may or may not occur). Even in the absence of innovation there is also at best only implicit and subjective certainty as to the probabilities with which states k=1,2 may be forthcoming. To see this more clearly and in order to examine ways in which such uncertainty might be systematically reduced by a regulator, now associate the indicated dual variables with the constraints of (VII) to derive Kuhn Tucker conditions (VIIa)'* which are analogous to (VI)':

Min $\quad 50\lambda_{r1i}+100\xi_{r11}+\eta_{ij}\,x_{r0}'+80\delta$

$y_{r1}\quad$ st $\quad 5\theta_1+\;3\theta_1\leq\varphi_{r1}$

$y_{r1}\quad\quad\quad 4\theta_1+\;2\theta_1\leq\varphi_{r2}$

$\rho\geq0 \quad\quad\quad\quad\quad \Sigma\theta_k\geq1$

$x_{r11}\quad\quad\quad \lambda_{r1}-5\varphi_{r1}\geq0$

$x_{ro}\quad\quad\quad \xi_{r11}-1.5\varphi_{r1}-2.5\varphi_{r0}\lambda_{r0}+\eta\geq0 \quad$ (VIIa)'*

$x_{r0}'\quad\quad\quad \theta_1 h_{r0}'+\theta_2 h_{r0}'-\eta\leq\delta$

$x_1^{rs},x_i^{sr-}\quad -\theta_1 h_{11}^{rs'}-\theta_2 h_{12}^{rs'}\leq\lambda_{r1}\leq\theta_1 h_{11}^{sr'}+\theta_2 h_{12}^{sr'}$

[The form of the first three constraints in (VIIa)'* is isomorphic with those of a minimax game formulation of the standard type. In that context the additional regulatory constraints in (VII)*' can be related in turn to the structure of a *constrained game.* For relationships between (VII) and (VII)' and these specializations via (VIIa)* and (VIIa)'* to constant sum games and constrained games see Charnes 1953, Charnes and Cooper 1961, Hazell 1970, Owen 1982, Ryan1995. In particular the explicitly framed and resource constrained cases in (VIIa)* can be seen as explicitly uncertainty related extensions of work in Ryan 1998 on framing and in Ryan 1994 on production scheduling under uncertainty.]

With reference to (VII), changes in regulatory regimes for firms deciding via (VII) may be introduced by regulators via dually related Kuhn-Tucker conditions (VII)' (which generalize conditions (VIIa)'*). In effect a regulator may change regulatory parameters in (VII)' as if purposively to tighten or loosen those constraints as if thereby to *induce* regulated firms using the dually related systems (VII) to change their production and distribution decisions in directions desired by the regulator. More directly, a regulator may reduce regulatory uncertainty, and at the same time may potentially gain closer co-ordination with the decisions of the regulated

industry, by explicitly specifying two kinds of probabilities. First: a regulator may specify values for the probabilities θ_k associated with fully specified potentially forthcoming states $k=1,2\ldots K_1$. Secondly; a regulator may implicitly specify values for conditional probabilities $\theta_k^{+},\theta_k^{-}$ of further not fully specified states $K_1\ldots K$ via an explicitly framed extension of (VII)'. These kinds of extensions are considered in more detail in Ryan 2000.

7 Conclusion

In this paper I have introduced new results and associated examples with emphasis on the role of regulatory uncertainty as distinct from regulatory risk in conditioning the behaviour of regulated enterprises. In that context new ways of modelling innovation and learning have been examined and systematic links between processes of innovation and learning and duality properties of associated optimization problems have been explored. While I have illustrated these ideas using linear examples I close by emphasizing that the systems (VII) and (VII)' and applications of them comprehend nonlinear cases.

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