Essays in applied microeconomic theory: crime and defence

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A thesis submitted in partial fulfilment of the requirements for the degree of Doctor of Philosophy in Economics

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October 2007

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Acknowledgements

This thesis has benefitted greatly from the advice of my supervisors: Myrna Wooders, Sayantan Ghosal and Norman Ireland. I am grateful for all the advice they have given me. I am also truly grateful for all the support I have been given by my mum and dad, and also by my sister.

Declaration

Initial thoughts on chapter two were formed during a MSc dissertation on "Pay the poor, reduce crime? Tax competition, labour mobility and crime" supervised by Myrna Wooders. They have been developed to form chapter two, though the literature review and some of the basic modeling is based on this paper. However all the tax competition results are original. An earlier version of chapter two was presented in the Public Economics Workshop at the University of Warwick. Earlier versions of chapters four and five were also presented at the Research Students Workshop at the University of Warwick. This thesis is my own work and has not been submitted for a degree at another university.

Abstract

The first part of this thesis is concerned with tax competition when the tax receipts fund an anti-crime measure. Both the capital and criminals are mobile between two jurisdictions. The resulting pure strategy Nash equilibrium tax rates are distorted from the optimal tax by the equilibrium migration response of the rich; if positive at the equilibrium then tax competition will result in taxes that are too high whilst if it is negative taxes will be too low compared to the optimum. The best response functions of the model are tested using data from England and Wales. The possibility that they engage in tax competition cannot be ruled out. It is possible for a central government to devolve tax raising powers without the distortion occurring if they can impose an optimal sanction. This, though, is independent of the harm caused by the crime and could be politically difficult to introduce.

The second part looks at the Ministry of Defence's procurement policy since 1985. The role of competition has increased but scant attention was played to the trade-off between maximising the benefits of current competition and obtaining future competition. The Ministry of Defence always chose to take the benefits in the short term arguing any loss of competition merely eliminated excess capacity which the Ministry of Defence would no longer have to pay for. Whilst the empirics suggest this is true during the 1990s, the problems encountered on the Type 45 project at the start of the millennium demonstrate the difficulties they have in procuring given the limited number of domestic firms they can contract with. An alternative mechanism of directed buys, with recourse to a competitive market off the equilibrium path, is suggested as a way in which the Ministry of Defence can preserve competition into the future.

Abbreviations

ALSL	Alternate landing ships logistic
AOR	Auxiliary Oiler Replenishment vessel
B2TC	Batch 2, Trafalgar Class submarines
BAe	British Aerospace
BM	Brooke Marine
CDP	Chief of Defence Procurement
CL	Cammell Laird
CNGF	Common New Generation Frigate
CVF	Future aircraft carrier
DC	Defence Committee of the House of Commons
DoD	US Department of Defense
DTI	Department of Trade and Industry
FOC	First of class
HR	Hall Russell
LPD	Landing Platform Dock
LPH	Landing Platform for Helicopters
MES	Marconi Electronic Systems
MMC	Monopolies and Mergers Commission
MoD	Ministry of Defence
NAO	National Audit Office
NAPNOC	No acceptable price, no contract
PAC	Public Accounts Committee of the House of Commons
PAAMS	Principal anti-air missile system
Ro-ro	Roll-on, roll-off ferries
SAC	Scottish Affairs Committee of the House of Commons

SCEC	House of Lords' Select Committee on the European Communities
SDE	Statement on Defence Estimates
SH	Swan Hunters
TIC	Trade and Industry Committee of the House of Commons
VT	Vosper Thornycroft
YSL	Yarrow Shipbuilders Limited

Chapter 1

Introduction

This thesis is concerned with two areas of microeconomics: tax competition when the tax receipts fund policing and the Ministry of Defence's recent naval procurement programme. These are two sets of key issues that face a government which, in their different ways, affect the security of its residents. The first concerns the level of government at which tax decisions ought to be taken when the tax receipts fund a police service to the benefit of the capital's owners. This is of particular relevance to the United Kingdom as central government distributes funds to police forces which the police forces themselves are able to supplement through local taxation. The question arises as to whether allowing local police forces to levy their own taxes results in suboptimal outcomes if they compete in taxes. The second issue concerns how a central government can manage the decline of an industry from which it is the sole purchaser and there are barriers to entry for new firms. Is it more efficient, if the firms possess different cost structures, to allow a monopoly to occur or is their a case for duopoly? In the United Kingdom the surface warship procurement programme was reduced in the 1990s causing some firms to leave the industry and now the Ministry of Defence only views two firms capable of building its vessels. The question arises as to whether this is one firm too many.

The approach adopted in this thesis is to firstly consider the current system in which policy makers determine their actions. Simple games were then applied to both sets of issues to help analyse them. Crime was introduced into a model of tax competition to see whether the local determination of taxes, if jurisdictions compete with one another, result in suboptimal

taxes being levied. For naval procurement a model is written to demonstrate an alternative procurement mechanism the Ministry of Defence can use to purchase vessels and achieve long term efficiency, though demonstrating the loss in short term efficiency. Finally both topics needed empirical investigation. The policy recommendations for which level of government ought to tax depends on whether there is any evidence of police authorities engaging in tax competition whilst the government's repeated assertion that competition was not being lost when the number of naval shipyards fell also needed testing. The remainder of this introduction gives more details on each part and the contents of each of the chapters. Discussion of the related literature is left to subsequent chapters.

Tax competition and policing

Previous studies of tax competition have focused on the tax receipts funding a public good or transfer payments. An alternative use of the tax receipts is to prevent a bad from occurring. The most obvious bad that can occur is if the capital itself is subject to some risk and therefore the tax receipts can be used to mitigate the risk. The risk considered is crime – the capital can be stolen so the tax funds a police force which lessens the risk of the capital being stolen. The question arises as to whether the presence of tax competition can distort taxes.

The first half of this thesis is concerned with tax competition and policing. The initial motivation for the paper came from the location of the University of Warwick. The university straddles two policing areas: West Midlands and Warwickshire. The governing body of each police force in England and Wales is able to set its own funding requirement. Although they receive transfers from central government any excess has to be recouped through the Council Tax of the police force's residents. Thus the police in either area are effectively able to determine their own taxes; in 2004/05 the difference between them for an average property (band D) was £46.47. There are also two major towns in which students reside: Leamington Spa (in Warwickshire) and Coventry (in the West Midlands). Therefore the question arises as to which jurisdiction would you choose to commit a crime in if you are criminally minded? Where is best to reside if you could potentially be a victim of crime, trading-off post tax

income against the level of security provided? Further there are interactions between the two groups which can influence where individuals reside. For example, an increase in the number of taxpayers can decrease the expected return from crime, if the level of policing increases.

Chapter two employs a modified version of Hindriks tax competition model (1999). It assumes one group of individuals receives a dividend income of one. They pay tax on their capital and are mobile between two jurisdictions. It is possible for the post tax income to be stolen from them by one of the criminals. The criminal group is also mobile between the jurisdictions, though they can only commit a crime in the jurisdiction in which they reside and do not pay tax. The resulting pure strategy Nash equilibrium taxes are distorted from the optimal by the equilibrium migration response of the taxpayers. Thus under- or over-taxation is possible compared to the optimal tax which would be levied by the federal government. The chapter then continues by presenting a linear version of the model to allow the best response functions to be determined. These are then tested empirically using data for the last five years from police authorities in England and Wales. Thus can the £46.47 difference in tax levels between the two police forces be explained by tax competition or by factors intrinsic to each jurisdiction? The results suggests the presence of tax competition between police authorities in England and Wales cannot be ruled out.

Chapter three presents a more generalised model of crime and tax competition, whereby holders of capital are mobile between jurisdictions but are subject to a crime unrelated to their capital. Again criminals are also mobile between the jurisdictions and the resulting pure strategy Nash equilibrium tax is distorted by the equilibrium migration response of the taxpayers to a change in the tax rate. The chapter then introduces changes to the model which demonstrate, with the use of a numerical example, how the resulting equilibrium tax responds to changes in the underlying assumptions. It also shows a couple of benefits that tax competition can bring, for example the possibility of increased funding for crimes when only a minority of the population is affected by them. A second crime is also introduced and the effect of competition between jurisdictions is again to misallocate resources between the

the two crimes. The chapter concludes by discussing which level of government is best placed to determine the tax rate.

UK naval procurement policy

The second part of the thesis is concerned with the Ministry of Defence's surface warship procurement strategy since 1985. With the end of the Cold War the size of the Royal Navy fleet has fallen so, as a consequence, the demand for new vessels also fell. This has meant the naval shipbuilding industry has had to contract. The government's policy of only purchasing domestically built hulls combined the barriers to entry for firms wishing to enter the market means the Ministry of Defence needs to manage the decline of the industry to ensure its long term interests are protected; there is the possibility that if the decline is left to the market then the short term efficiency can be offset by the long-term inefficiency that results if the wrong yards survive. Therefore this part of the thesis is also composed of two chapters. The first looks at how future projects influenced naval procurement decisions; whether long term efficiency considerations ever outweighed the short term cost savings. The second presents a procurement mechanism for an industry in decline with a sole purchaser of their products which maintains competitive pressures but ensures longer-term value for money is achieved.

Chapter four describes how the procurement policy has evolved since the early 1980s when British Shipbuilders, the nationalised monopoly, was the only domestic firm the Ministry of Defence could order its ships from. The government privatised the warship yards first as they were the most profitable. Privatisation brought increased competition to the sector and, according to the Ministry of Defence, lowered the price paid for ships. After the end of the Cold War the demand for ships fell further and some of the yards closed. Whilst aware of the possible consequences on future prices, the Ministry of Defence continued to pursue competition for procurement contracts insisting when any firm left the industry it would have no effect on future prices. Thus short term considerations always took precedent over longer term concerns. The chapter considers how this has influenced the procurement policy for the current expanded naval procurement programme, with only two yards currently considered for

naval contracts in the UK. The chapter concludes by considering whether or not the Ministry of Defence's assertion regarding the loss of competition and prices is correct.

Chapter five follows by asking whether the process of contraction ought to continue leaving only one domestic firm able to construct vessels. The model assumes a vessel takes two periods to build and is perfectly divisible in each period. Furthermore it assumes only two firms, each possessing a different cost, remain and if one receives no work in the first period it is unable to compete for work in the second period. The game proceeds by the government offering one firm a portion of the project for a price which they can either accept or reject. If they reject the same contract is offered to the other firm. If they too reject the contract is auctioned until one firm accepts. The solution is for the government to offer contracts with prices whereby the dominant strategy for each firm is to accept the contract, otherwise the other firm will accept forcing the firm to leave the industry. The simple game suggests both firms remaining in the industry is beneficial and can even be cheaper than auctioning a complete contract for the whole project in period one. Although this procurement mechanism allows the possibility of one firm earning a supernormal profit in the presence of full information, it ensures there is no preferential treatment between the firms (so both can view it as being fair) and is sufficiently simple for the Ministry of Defence to introduce.

Chapter six concludes and offers thoughts on where this research can go next.

Part I

Tax competition and crime

Chapter 2

Property crime and tax competition

Responsibility for the police in England and Wales is shared between central government, the local police authorities and the Chief Constable of each police force. The balance amongst the constituents of this tripartite relationship changed after the introduction of the Police Reform Act 2002. The Police Act 1964 formalised the notion already written in case law of constabulary independence; each police force has operational independence from central government in pursuit of the maintenance of law and order. However central government still had a major input as the main finance provider for each police force. The Police Reform Act 2002 allows for central government to stipulate a National Policing Plan with associated targets which have to be taken into account by the Chief Constable thus extending their role into the operation of police forces.

Loveday and Reid (2003) argue that this merely continues a process of centralisation that has been occurring over the last 50 years. They cite the number of police forces the England and Wales has decreased from 126 in 1968 to 43 today. Concurrent with this they suggest the level of influence local communities have in determining the police service provided has also fallen (with the reduction of the size of police authorities from 35 members to 17). This denigrates an important role police authorities still possess – the budget. Although about 85% of a police force's budget comes from central government, subject to excessive spending constraints each authority is able to determine its own budget. This in turn will have an effect on the level of implementation of centrally determined priorities.

In determining the local budget the police authority has the power to issue a precept payable as part of the Council Tax. A Tiebout model would suggest jurisdictions provide different levels of security and the rich and criminals would then locate according to their preferences. However if people have preferences for a particular jurisdiction independent of the tax/anti-crime measure combination on offer (for instance people have an attachment to home measure in their utility functions) then the issue for the jurisdictions' governments is how can the optimal taxes be determined taking these into account when people are mobile across the jurisdictions.

This paper is based on the notion that the anti-crime measure is determined by central government though the extent to which it is funded is determined locally. People are mobile between the jurisdictions, settling in the jurisdiction that maximises their expected utility. The jurisdictions compete in taxes to attract the mobile capital (rich people) to settle in their jurisdiction. This chapter differs from Marceau (1997) by allowing not only the capital to be mobile but criminals, who commit crimes for economic reasons, as well. Under Marceau's model the tax competition results in too many resources being spent on crime fighting relative to the Pareto optimum.

The theory considers four anti-crime measures: benefit payments, fines related to the amount stolen, fines unrelated to the amount stolen and imprisonment. The proposed transfer payments are an act of impure altruism on behalf of the rich population as they act like a bribe; if crime is motivated by economic circumstances then means tested benefits should take some people out of the position where they have to commit crime. To go along with the carrot are three sticks used by the legal system as retribution for crimes. Fines related to the amount stolen are linked to the tax rate whilst fines unrelated to the amount stolen require the payment of a fixed fine. The third punishment strategy is imprisonment. This removes some criminals from society (reducing the numbers available to commit crime in any given period). This chapter also differs from Marceau (1997) by allowing these measures to have a deterrent effect; an increase in the funding of an anti-crime measure in a jurisdiction can stop

some criminals from committing a crime.

The paper proceeds as follows. Section 1 gives a brief overview of the relevant literature. Section 2 introduces the model for a single jurisdictional economy whilst section 3 does likewise for a two jurisdiction economy competing in taxes. Section 4 gives some extensions and policy implications before section 5 investigates whether there is currently any tax competition taking place between police forces in England and Wales. Section 7 concludes.

2.1 Previous work

For a long time there has been investigation into the roots of crime. Some have felt that people are born with criminal tendencies whilst others believe the environment in which they are raised is the cause.[1] However the seminal work on the economics of crime was written by Becker (1968). He developed a principal-agent model, whereby rational agents respond to incentives – people undertake criminal activities not because of intrinsic characteristics, rather as a result of utility maximising behaviour. A person can either undertake legal employment with a known return or illegal activities with uncertain returns; earnings are monotonically related to the time spent in each (and both are perfect substitutes with no spill-over effects). Agents know the probability they will be apprehended and the punishment that will follow (expressed in monetary terms). With this information they then make their decision on whether or not to participate in crime.

The economic model of crime has been rigorously tested. The general conclusion of empirical testing is that the crime rate is lowered when deterrent measures are increased.[2] The tests do, however, report different magnitudes of the effect on the crime rate increasing the

[1]The nature argument can be traced to Darwin's The Origin of Species (1859), which suggests an animal's characteristics are determined at birth and cannot be altered. The nurture argument suggests that animals are conditioned by the society and environment they are raised in. Singer et al. (1998) attribute this argument to "the Romantic movement, in particular the writings of Jena-Jacques Roussea (eg The New Heloise in 1761 and Emile in 1762)"(page 633.

[2]One exception is Myers (1983) who finds severity of punishment is only weakly related to crime and increases in the certainty of punishment are positively related to participation in crime. The estimation, though, has been criticised by Witte (1983).

probability of arrest or increasing the sanction imposed if caught has. Davis (1988), Mathur (1978), Sjoquist (1973) and Witte (1980) all report that increasing the probability of arrest deters more crime than a comparable increase in the severity of the sanction. However a debate remains as to whether increasing the size of the police force has an effect on the crime rate through increasing the probability of arrest.

Police numbers are weakly endogenous to changes in the crime rate according to Cameron (1988) due to the endogeneity of hiring police; a common public policy response to rising crime is to hire more police. Levitt (1997) finds the mean percentage change in sworn police officers in mayoral election years is 2.0%, compared to 0.0% in non-election years. However increased police officers do reduce the crime rate (an additional officer results in 1.6 to 12.4 fewer property crimes). This view is supported by Tauchen et al (1994), where the deterrent effect is even greater for those with no previous contact with the law. Mathur (1978) finds police expenditure is neither a crime deterrent nor does it increase the probability of arrest. Sherman (1992) reports evidence suggesting police actions can reduce, increase or make no difference to the crime rate depending on the model specification used.

There are however criticisms of the estimation techniques. The early empirical work used aggregated data when trying to test a model based on individual choice. Unfortunately reliable and detailed panel data sets have not existed for a sufficiently lengthy period to fully test the model. Cornwell and Turnbull (1994) argue that omitted heterogeneity of aggregate data leads to an upwards bias in the effectiveness of the deterrents (whereas panel data can control for this). Corman, Joyce and Lovitch (1987) suggest deterrence variables and the crime rate are integrated and the presence of multicolinearity makes it difficult to assess the relative contributions of deterrence variables and employment variables. However all empirical investigations suffer from basic problems with the data used: not all crimes are recorded (Levitt (1996) states only 38% are) and not all criminals are caught.

Criticisms have not been limited to the empirical methodology. Block and Lind (1975a, 1975b) presented theoretical objections. In the former they argue punishment cannot always

be expressed in monetary equivalents; in the latter preferences of the poor are important. Assuming the cost of crime to be independent of wealth, if the population was ordered according to its legal wealth (equivalent to current assets and discounted future earnings), the percentage of individuals engaged in crime would decrease as wealth increases. However when wealth consists only of future earnings, an "increase in legal earnings will have a larger deterrent effect than an equal increase in transfer payments for some crimes and no smaller effect for any crime" (page 488). Thus an increase in future legal earnings has a greater deterrent effect than a corresponding increase in benefit payments. Further, proportional changes in the probability of apprehension have a greater deterrent effect than proportional changes in sentencing. Phillips (1972) and Myers (1983) find evidence to support this. Other models of criminal behaviour have also been presented. Ehrlich (1973) uses a state-preference model in which individuals choose the amount of time to devote to illegal activities. The effectiveness of any public policy response is dependent on the extent to which people are involved in criminal activity. Block and Heineke (1975), as reported by Pyle (1983), include the amount of time directly devoted to legal and illegal activities in wealth. The deterrence theory is more ambiguous with the response dependent on the preference for honesty.

If people choose to commit a crime but are caught there are two sanctions available: fines or incarceration. Becker argues fines are the optimal form of punishment as they are socially costless; optimal fines at the margin fully compensate the victim whereas incarceration requires the victim to be economically punished as well – incarceration has to be paid for by taxpayers and uses social resources. The optimal fine depends on the marginal harm and the cost, not on the perpetrator's ability to pay. Further it is independent of motivation or intent behind the crime. If a criminal is unable to pay the fine, then the option of sending them to prison remains.

Economically, incarceration ought to give the exact same loss of utility as fines. However Becker suggests the rate of exchange between fines and time spent in prison places too low a value on the latter. If fines are the price of an offence in monetary terms then incarceration

should be the price expressed in terms of time. Block and Lind (1975a) argue that despite the difficulty in exchanging monetary and time terms, the status quo is correct as it encourages people to pay fines rather than be sent to prison. Ehrlich (1981) argues if the social cost of punishment by fines is zero and the criminal can afford to pay them, then fines are far superior to incarceration. However as the social cost of fines is generally greater than zero (due to administration costs and evasion in payment by the criminals), if the elasticity of the equilibrium crime rate with respect to imprisonment is sufficiently greater than the elasticity with respect to fines, fines should be replaced by, or used in conjunction with, incarceration.

Polinsky and Shavell (1984) support the Becker view and find fines are more socially beneficial than imprisonment. When considering different income groups, the rich ought to be fined more (although the amount of time they should spend incarcerated is uncertain). If individuals are risk averse (as Ehrlich (1973) finds), the probability of apprehension should be higher and the sanction lower. Levitt (1996) finds increasing the prison population by one reduces the number of crimes committed by 5.54. Of this total, 2.6 are crimes of larceny and 1.3 are burglaries. (Due to only 38% of crimes being reported, the true figure is 15 which is the same as the median number obtained from prisoner surveys). In a later paper (1998), he finds when a juvenile reaches the age of majority in states that punish adults particularly harshly relative to juveniles, the juveniles' violent crime rate drops 25% and property crime rate falls by 10 to 15%.

The second major area of literature relevant to this, and the next, chapter concerns multi jurisdictional economies and tax competition. Tiebout (1956) argued that competition amongst jurisdictions in providing public goods can deliver an efficient outcome if households are mobile. The mobility of households allows them to 'vote with their feet' and reside in the jurisdiction that offers their preferred fiscal package. However the Tiebout hypothesis has been much critiqued due to the underlying assumptions; indeed Oates (1981, page 93) described the assumptions underpinning the model as "so patently unrealistic as to verge on the outrageous".

Oates (1972) argued that an inefficiently low level of public goods will be provided if jurisdictions compete for business capital due to the presence of a fiscal externality between the jurisdictions (the existence of which is ruled out by Tiebout). The government of a jurisdiction has to take into account the possibility of capital leaving the jurisdiction dependent on the tax level chosen; it is assumed the amount of capital in the global economy is fixed. Capital flight increases the marginal cost of any tax resulting in a lower level of public goods being provided. Since all jurisdictions face the same incentives, all will provide an inefficiently low level of public goods. Zodrow and Mieszkowski (1986) provided the first formal model.

It is the presence of these interjurisdictional externalities that led to the early literature finding that tax competition results in inefficiencies, as reported in Wilson's survey (1999). However he states more recent contributions have suggested tax competition can be efficiency enhancing, for example where there are imperfectly competitive market structures or political economy considerations. Contributions to the literature on redistribution and tax competition have disagreed on whether local governments can or cannot redistribute efficiently.

The model in both this and the next chapter is based on Hindriks' model (1999). His paper allows two groups of individuals, rich and poor, to be simultaneously mobile across two jurisdictions. The aim of each jurisdiction's government is to redistribute income from the rich to the poor, with individuals moving between the jurisdictions depending on the tax or benefit provided by each jurisdiction. As would be expected, increasing the mobility of the rich decreases the equilibrium tax rates as the elasticity of the tax base increases. Generally, increasing the mobility of the poor also hinders redistribution, though this is not always the case. Hindriks also finds, like Wildasin (1988), that when jurisdictions compete in taxes there will be less redistribution than when they compete in benefits. In comparison to these inefficient outcomes when local jurisdictions redistribute income, Pauly (1973) found redistribution by local governments can be Pareto efficient when some individuals are immobile and the income level of the poor enters the utility function of the rich. This utility interdependence is not necessarily born from altruism, rather for other reasons, for example poverty offending

aesthetic and moral sensibilities and possible reductions in crime.

To link these two areas, crime and tax competition, there are papers that focus on the spatial aspects of crime and policing. Deutsch et al. (1987) present a model showing how a criminal decides in which jurisdiction to commit their crime. The strategy that criminals follow is to start in a jurisdiction where the probability of success is the greatest but returns are the lowest before moving to crimes which have a greater return. The final crime committed has the highest return of all but the least probability of success.

Mehay (1977) studies the effects of spillovers in crime expenditure. The model presented takes the other jurisdiction's spending as given and finds the best response. Hakim et al. (1979) allow for the jurisdictions to be playing a Nash equilibrium in terms of crime expenditure. The spillover effect can be either positive or negative. They estimate there is a small crime expenditure spillover of around $0.05 in each dollar. Marceau (1997) looks at a micro founded model of crime expenditure as a deterrent between jurisdictions. He finds that if either criminals or capital are mobile across jurisdictions then there will be a Pareto suboptimal level of crime deterrence. However the Nash equilibrium is not one of under-provision rather too many resources are devoted to the fight against crime. He does not extend his model so both capital and criminals are mobile across jurisdictions. The model below allows this when searching for the Nash equilibrium. The idea that crime can influence the location choice of individuals comes from Cullen and Levitt (1996). They seek to explain urban flight from American cities using crime. The aggregated data shows a correlation between outwards migration from cities and changes in the crime rate. Further workings suggest that there is a causal link between the two, with crime being the cause of the urban flight. The panel data looks at similar issues, finding that rich households are five times more responsive to changes in the crime rate than poor households. Thus crime would appear to be a motivator for migration, though not of a great distance as the majority occurs as urban flight, ie merely relocating in the suburbs. Although they look at the likely fiscal effects this urban flight causes (a downwards spiral) they do not include local taxes as a variable.

2.2 Crime in a single jurisdictional economy

The model assumes crime is motivated by economic circumstances; poor people commit offences against the rich in order to gain income. Let there be n_1 poor people who have no income and n_2 rich people with a dividend income of one with $n_1 < n_2$.[3] The poor can obtain income in two ways: benefits or crime.[4] Benefits are a transfer payments from the rich to the poor. These transfers represent impure altruism; if economic circumstances dictate whether or not a poor person participates in crime, paying benefits can prevent some crimes. The poor's second source of income is stealing from the rich. It is assumed there are no financial institutions in which money can be deposited so money has to be carried around in pockets or left at home. Although a criminal can steal from both, he is only able to attempt to commit one crime during the tax period. The rich and poor are easily distinguishable by sight.

Not all the poor are necessarily criminals; the decision of whether or not to participate in illegal activities is determined endogenously. Assume each poor person has a reservation level of income, b where $b \in \left[\underline{b}, \overline{b}\right]$. How b is distributed amongst poor people is common knowledge, however the authorities do not know any individual's reservation valuation. Thus if a benefit of level B is paid then any poor individual j will be a thief if $B < b_j$, otherwise he will be law abiding.[5] It is assumed that only the rich are victims; successful criminals cannot themselves be subject to crime. Further, a criminal is always successful in his endeavours.[6]

Assuming there is a requirement for the government to maintain a balanced budget then $B = \frac{tn_2}{n_1}$. Although the poor are more concerned with the benefit paid to them than the tax rate, in a single jurisdiction with a fixed population and a balanced budget, the transfer payment is directly proportional to the tax rate (as $\frac{n_2}{n_1}$ is fixed). This means a well defined propensity to commit crime function exists that depends on the tax rate levied in the jurisdic-

[3]The subscript one denotes the poor and two the rich throughout this chapter.

[4]It is assumed that crime is committed for the money rather than to gain the other instantaneous rewards that can come with it; drugs, status and sex (DeIulio, 1996).

[5]As the income of a poor person has been normalised to zero only the level of the benefit paid is of interest.

[6]This can be viewed as an extension of the labour choice model. As there are no legal earning opportunities for the poor, they can devote all of their time to criminal activities. The specialisation that results ensures success in their endeavours.

tion, $p(t)$. The propensity to commit crime is the probability any poor person will commit an act of crime during one period of time. If $\overline{b} < 0$ then there will be no crime in the jurisdiction; if $\underline{b} > 0$ then all poor people will be criminals if no benefit is paid. Assume $\underline{b} < 0$ and $\overline{b} > 0$. An increase in the tax rate increases the funds available for redistribution causing the number of people for whom $b_j < B$ to fall which means there are fewer criminals. Thus $\frac{\partial p(t)}{\partial t} < 0$.

So far benefits have been the only crime reduction method. An alternative is to fund a police force and apply criminal sanctions if an individual is caught. In the absence of any transfer payment there is a fixed proportion of the poor prepared to commit a crime in order to increase their income. However the possibility of any legal sanction, l, expressed in monetary terms by e_{jl}, enters the utility function of a potential criminal. Assume the distribution of e is known by the government but the draws are private, where $e_j \in [\underline{e}, \overline{e}]$. A poor person will then decide to commit a crime if $1 - t - ze_{jl} > 0$, where z the probability of the sanction being implemented. As z is dependent on the tax rate levied by the government (the more funds the police receive the more crime they are able to prevent or detect) another propensity to commit crime function exists, $p(t)$, with $\frac{\partial p(t)}{\partial t} < 0$ (any increase in the tax rate lowers the expected return from crime by lowering the return if successful and increasing the probability of a sanction being applied).

Assume the government is seeking re-election. As $n_2 > n_1$ this implies, via the median voter theory, the government seeks to maximise the utility of the rich individuals.[7] Rich individuals are unable to take any private action to reduce p; the only mechanisms come from the state.[8] The expected utility of a rich person (u_2) is given by

$$u_2 = (1 - t)\left(1 - \frac{pn_1}{n_2}\right) \tag{2.1}$$

where t is the tax rate levied.[9] This expresses utility purely in terms of the expected utility of money and does not allow for other factors, for example the fear crime can engender.

[7] Assuming the rich only vote over the level of taxation.

[8] Goldberg and Nold (1980) find that households which are more likely to report crime are less likely to be the victims of crime.

[9] Although the words tax rate are used, as there has been a normalisation of income the tax rate is equivalent to a lumpsum tax.

The second bracket represents the probability a rich individual will not be a victim of crime during one period of time (hence the probability he will retain his money). This probability is increasing in n_2 but decreasing in $p$and n_1; as the number of criminals (given by pn_1) increases relative to the number of rich people the likelihood anyone of them is a victim increases. Thus in determining the tax rate the government, on behalf of its voters, has to trade-off post tax income against the security tax receipts can fund.

In the absence of a government the expected utility of a rich individual is the probability he retains his money (as t equals zero). Given there are no transfer payments nor a police force with sanctions, p is simply the proportion of poor individuals who have a value of b greater than zero.

2.2.1 Transfer payments

Now assume there is a government. The first crime reduction mechanism they can use is transfer payments. Under this specification, the utility function of the rich is

$$u_2 = (1-t)\left[1 - \frac{p(t)n_1}{n_2}\right]. \tag{2.2}$$

Due to the utility function always being concave if $p(t)$ is convex[10], the tax rate which maximises the rich's utility function solves

$$t = \frac{n_1\left[\frac{\partial p(t)}{\partial t}\right] + n_2 - p(t)n_1}{n_1\left[\frac{\partial p(t)}{\partial t}\right]}.$$

However this is unbounded so t can take on values below zero.[11] As only positive rates of tax can be levied ($0 \leq t \leq 1$), the constrained tax rate solves

$$t = \max\left\{0; \frac{n_1\left[\frac{\partial p(t)}{\partial t}\right] + n_2 - p(t)n_1}{n_1\left[\frac{\partial p(t)}{\partial t}\right]}\right\}. \tag{2.3}$$

Taxes will only be levied on the rich if $-\left[\frac{\partial p(t)}{\partial t}\right] \geq \frac{n_2 - p(t)n_1}{n_1}$. Thus in order for there to be a tax the reduction in the propensity to commit crime must be greater than the ratio of the

[10]The necessary condition for concavity is $2\left[\frac{\delta p(t)}{\partial t}\right] < (1-t)\left[\frac{\partial^2 p(t)}{\partial t^2}\right]$. As the first derivative of $p(t)$ is always negative, this will always hold if $p(t)$ is convex.

[11]It cannot take on values above one as this would require $p(t)n_1 > n_2$, which the restrictions of the model setup do not allow.

number of rich individuals who are not victims of crime to the number of poor people. In other words the probability of being a victim of crime has to be sufficiently high to warrant a tax being levied. If it is not high enough then the rich would rather risk being a victim of crime than pay the poor any benefit as the threat is just too low (or the effectiveness of paying benefits as an anti-crime measure is too low). Thus the greater n_1, the greater the tax levied.

2.2.2 Fines

A police force can serve two functions in society; crime prevention and crime investigation. The previous section is analogous to the police force solely having a prevention role. Tax receipts fund a police force able to prevent crime either by patrolling and having a high visibility or by informing rich individuals on crime prevention techniques. Either way the opportunities to commit crime are reduced thus decreasing the probability any poor person commits a crime. As such the optimal tax rate is still given by (2.3), although the propensity to commit crime function will be different. Therefore the question arises which is more effective in giving the rich a higher expected utility, transfer payments or crime prevention. The answer to this lies in the specification of $p(t)$ under each: how much can crime be reduced through one unit of funding? With transfer payments some people are being brought out of crime altogether whilst prevention only limits the extent to which crime can be committed.

The police, however, can also investigate crime and detect criminals after it has been committed. After a rich individual has become a victim of crime they can report the incident to the police who then investigate it, given the funds available. If the investigation is successful, the criminal will be brought before a court and tried. If convicted he will be required to compensate the victim by either paying an amount related to the sum stolen or an unrelated punitive fine. To model this process assume all crimes are reported. Further assume everyone arrested by the police has committed the crime and accordingly is found guilty by the courts (so a sanction is imposed). The success rate of the police's investigations is a probability,

dependent on police funding (as measured by the tax rate), $z(t)$, where $z(0) = 0$ and $\left[\frac{\partial z(t)}{\partial t}\right] > 0$.[12] If crimes are not always reported or prosecutions are not always successful this can be incorporated by a lower value of $z(t)$ for each tax rate (assuming no one's utility decreases if someone is wrongly prosecuted).

Fines related to the amount stolen

If the government chooses to punish criminals by levying fines proportional to the amount they have stolen, $h(1-t)$ where h is a constant expressing how much they are punished, the utility function of the rich is given by

$$u_2 = (1-t)\left[1-(1-hz)\frac{p(t)n_1}{n_2}\right]. \tag{2.4}$$

The utility of a poor person randomly drawn from the population is $u_1 = p(1-hz)(1-t)$. If h is low, so $h < \frac{1}{z}$, then $u_1 > 0$ meaning it is possible for p to be fixed as a greater expected utility results from attempting to commit crime than doing nothing; thus e could represent the expected loss a criminal is prepared to bear if he commits a crime. Alternatively, if personal stigma is attached to being caught then it is possible that crime can be deterred even when the expected pay-off is positive, meaning $\frac{\partial p}{\partial t} < 0$. For larger values of h the expected return from crime is negative which will always deter some. This model assumes there is no default in the payment of fines; although this can be included in h (so h is the multiple of the fine and the probability it is paid). The possibility of default is considered in the next subsection.

If p is convex in t and z concave then the utility of a rich individual is concave in t if hz is sufficiently small.[13] Assuming the utility of the rich is concave in t then the optimal tax solves

$$t = \frac{-n_2 + pn_1(1-hz) + pn_1h\left[\frac{\partial z}{\partial t}\right] - n_1(1-hz)\left[\frac{\partial p}{\partial t}\right]}{pn_1h\left[\frac{\partial z}{\partial t}\right] - n_1(1-hz)\left[\frac{\partial p}{\partial t}\right]}.$$

[12]The poor are informed and know the true $z(t)$ so the perception of punishment equals the reality (as opposed to Sah (1991) where criminal decisions can be based on lack of knowledge). This assumption is relaxed in the next chapter.

[13]The necessary conditions for the tax rate to maximise utility is $-2[hp\left[\frac{\partial z}{\partial t}\right] - (1-hz)\left[\frac{\partial p}{\partial t}\right]] - (1-t)[(1-hz)\left[\frac{\partial^2 p}{\partial t^2}\right] - hp\left[\frac{\partial^2 z}{\partial t^2}\right] - 2h\left[\frac{\partial p}{\partial t}\right]\left[\frac{\partial z}{\partial t}\right]] < 0$.

However this is an unconstrained tax rate; the tax the government can levy can only be between zero and one. As the optimum tax cannot take on a value above one [14] the tax rate that maximises the utility of the rich is given by

$$t = \max\left\{0, \frac{-n_2 + pn_1(1-hz) + pn_1 h\left[\frac{\partial z}{\partial t}\right] - n_1(1-hz)\left[\frac{\partial p}{\partial t}\right]}{pn_1 h\left[\frac{\partial z}{\partial t}\right] - n_1(1-hz)\left[\frac{\partial p}{\partial t}\right]}\right\}. \tag{2.5}$$

The optimal tax has the properties of the previous tax, namely a tax will only be levied if the likelihood of a rich individual being a victim of crime is sufficiently high. When the poor are a minority the threat is sufficiently low not to warrant state intervention whereas this becomes necessary as their number, relative to the number of rich individuals, increases. Whilst the right-hand side is decreasing in h the response of the optimal tax is unknown and depends on the specification of the probability functions.

Fines unrelated to the amount stolen

Alternatively the government could choose to punish convicted criminals by imposing punitive fines unrelated to the amount stolen. The magnitude of the fine is f, where $f \geq 0$. The previous subsection mentioned the possibility of default; as there is no upper limit placed on f it is possible that a criminal is unable to pay the fine imposed on them if caught. Let $q(f)$ be the probability a convicted criminal does not default in the payment of the fine, where $q(0) = 1$, $q(\infty) = 0$ and $\frac{\partial q(f)}{\partial f} < 0$. Since the participation decision depends on the expected return from crime (which is influenced by the extent to which the police force is funded and the fine imposed if caught), the propensity of the poor to commit crime will be a function of the level of the fine and the probability of being arrested, $p(t, f)$. Therefore the utility function of a rich individual is given by

$$u_2 = (1-t)\left[1 - \frac{p(t,f)n_1}{n_2}\right] + z(t)q(f)f\left[\frac{p(t,f)n_1}{n_2}\right]. \tag{2.6}$$

[14] The tax rate is unable to take on a value above one as this would require $-n_2 + pn_1(1-hz) > 0$ which never holds.

The utility function ought to be concave if $p(t,f)$ is convex in t and $z(t)$ is concave (as in previous sections).[15] The utility maximising tax rate for the which solves

$$t = \frac{n_1\left[\frac{\partial p}{\partial t}\right] - n_1 q f(p\left[\frac{\partial z}{\partial t}\right] + z\left[\frac{\partial p}{\partial t}\right]) + n_2 - pn_1}{n_1\left[\frac{\partial p}{\partial t}\right]}$$

where f is exogenous.[16] However this is the unconstrained tax rate as t can take on values below one and above zero. Therefore the constrained tax rate solves

$$t = \begin{cases} 1 & \text{if } \frac{n_2 - pn_1}{n_1 q f(p\left[\frac{\partial z}{\partial t}\right] + z\left[\frac{\partial p}{\partial t}\right])} < 1 \\ \frac{n_1\left[\frac{\partial p}{\partial t}\right] - n_1 q f(p\left[\frac{\partial z}{\partial t}\right] + z\left[\frac{\partial p}{\partial t}\right]) + n_2 - pn_1}{n_1\left[\frac{\partial p}{\partial t}\right]} & \text{if } 1 \leq \frac{n_2 - pn_1}{n_1 q f(p\left[\frac{\partial z}{\partial t}\right] + z\left[\frac{\partial p}{\partial t}\right])} \leq 1 - \frac{n_1\left[\frac{\partial p}{\partial t}\right]}{n_1 q f(p\left[\frac{\partial z}{\partial t}\right] + z\left[\frac{\partial p}{\partial t}\right])} \\ 0 & \text{otherwise.} \end{cases} \tag{2.7}$$

The possibility of the tax rate being one is paradoxical. If the expected compensation is sufficiently high then the rich would want to become victims of crime because criminals, if caught, have to pay a high ratio of the amount stolen back to the victims in compensation. In order for the rich to benefit from these elevated levels of compensation the police force has to be able to catch the criminals, necessitating a high tax rate so they can be fully funded. However the paradox kicks in when $t = 1$ as there is no income left to be stolen so no compensation can be paid. Thus in practice the tax rate can approach one but not reach it. In order for the optimal tax to be levied the likelihood of being a victim of crime has to be sufficiently high to warrant a police force, for example n_1 needs to be sufficiently high. This is for the same reason as when benefits are used as an anti-crime measure; when the poor are a small minority the rich do not need protection as the poor do not represent a significant threat. However as they become more numerous, the threat increases so the rich start to fund a police force to protect

[15] The necessary condition for the utility function to be concave is $2\left[\frac{\partial p}{\partial t}\right] - (1-t-zqf)\left[\frac{\partial^2 p}{\partial t^2}\right] + pqf\left[\frac{\partial^2 z}{\partial t^2}\right] + 2qf\left[\frac{\partial p}{\partial t}\right] \leq 0$. If $p(t,f)$ is convex and $z(t)$ concave, then this should hold for the majority of cases.

[16] If equation (2.6) is maximised with respect to f (taking t to be exogenous), then the optimal fine for a single jurisdictional economy to levy is

$$f = \frac{(1-T)\left[\frac{\partial p}{\partial f}\right] - pqz}{qz\left[\frac{\partial p}{\partial f}\right] + pz\left[\frac{\partial q}{\partial f}\right]}.$$

This is a maximum providing $-(1-t-zqf)\left[\frac{\partial^2 p}{\partial f^2}\right] + pzf\left[\frac{\partial^2 q}{\partial f^2}\right] + 2pz\left[\frac{\partial q}{\partial f}\right] + 2zq\left[\frac{\partial p}{\partial f}\right] + 2zf\left[\frac{\partial p}{\partial f}\right]\left[\frac{\partial q}{\partial f}\right] < 0$. Although this does not always hold if $q(f)$ is concave in f it helps. If the second order condition does not hold then the government would seek to impose ever larger fines.

themselves. The police force also needs to be sufficiently effective if the rich are to fund it, as expressed through $\left[\frac{\partial z}{\partial t}\right]$. The role of the fine in the tax rate is ambiguous. The right-hand side of the optimal tax is increasing in f if $p\left[\frac{\partial z}{\partial t}\right] > -z\left[\frac{\partial p}{\partial t}\right]$. Thus the specification of the two functions will determine which effect dominates and how the optimal tax responds to the fine.

2.2.3 Incarceration

The final anti-crime measure considered is incarceration. Prisons help to reduce the probability of being a victim of crime in two ways. The first is to reduce the number of poor people in the jurisdiction thus making it less likely any one rich individual becomes a victim of crime. The second is to increase the deterrent (resulting from the loss of liberty if caught and convicted) and lower the propensity to commit crime by increasing the sanction and lowering the expected return from crime. Despite the advantages prison holds over the other anti-crime measures it also has one significant disadvantage, namely it requires tax payers to fund them. Whereas the payment of fines can compensate the victim for their monetary loss, prisons require the tax rate to rise further.

For the model again assume all crime is reported and if the police catch a person he is guilty and will be found so by the courts. If found guilty he is incarcerated for one period of time. The rich individuals pay taxes to fund a police force at the beginning of the time period. They also have to pay an additional amount to house the criminals that are caught. Therefore the utility function of a rich individual is given by

$$u_2 = (1 - t - k)\left\{1 - \frac{p(t)n_1[1 - z(t)]}{n_2}\right\} \tag{2.8}$$

where $k(t)$ is the amount each rich person is required to pay towards the cost of prisons and $p(t)$ the propensity of the poor not in prison to commit crime. During each time period there will be $n_1 z(t)$ criminals incarcerated from the previous time period. As such this can be thought of as the stage game of a repeated game. It is assumed that $k(t)$ is convex in the

number of criminals caught, as there is congestion in housing more prisoners.[17] The tax rate which maximises (2.8) solves

$$t = \frac{-(1 + \left[\frac{\partial k}{\partial t}\right])[n_2 - pn_1(1-z)] + (1-k)[pn_1\left[\frac{\partial z}{\partial t}\right] - n_1(1-z)\left[\frac{\partial p}{\partial t}\right]]}{pn_1\left[\frac{\partial z}{\partial t}\right] - n_1(1-z)\left[\frac{\partial p}{\partial t}\right]}.$$

This expression is the unconstrained tax rate as a government is unable to levy a negative tax rate.[18] Therefore the tax rate which maximises the utility of the rich solves

$$t = \max\left\{0; \frac{-(1 + \left[\frac{\partial k}{\partial t}\right])[n_2 - pn_1(1-z)] + (1-k)[pn_1\left[\frac{\partial z}{\partial t}\right] - n_1(1-z)\left[\frac{\partial p}{\partial t}\right]]}{pn_1\left[\frac{\partial z}{\partial t}\right] - n_1(1-z)\left[\frac{\partial p}{\partial t}\right]}\right\}. \quad (2.9)$$

As usual the government will only levy a tax if the number of active criminals is sufficiently high relative to the number of potential victims. The right-hand side of the optimal tax is decreasing in the cost and marginal cost of housing criminals; as the sanction is no longer costless any increase in costs corresponds to a lower tax rate as the rich would prefer fewer criminals be caught due to the increased costs of housing them.

2.3 Crime in a multi jurisdictional economy

The previous section introduced the base crime models. Now assume that tax decisions are devolved from the federal government to local jurisdictions' governments. Assume the country is composed of two symmetric jurisdictions, each with the capacity to house the entire population located. For ease of exposition the two jurisdictions are called the domestic and foreign jurisdictions.[19] The two jurisdictions are located at either end of a unit interval. Individuals possess a preference for a jurisdiction by a taste parameter, $x \in [0,1]$. A stronger preference for the domestic jurisdiction is represented by a lower value of x, a stronger preference for the foreign jurisdiction by a higher x. A value of x of one half represents no real preference

[17] The necessary condition to find a maximum for u_2 is $-\left[\frac{\partial^2 k}{\partial t^2}\right][n_2 - pn(1-z)] + (1-k)[2n_1\left[\frac{\partial p}{\partial t}\right]\left[\frac{\partial z}{\partial t}\right] + pn_1\left[\frac{\partial^2 z}{\partial t^2}\right] - n_1(1-z)\left[\frac{\partial^2 p}{\partial t^2}\right]]$. Assuming $p(t)$ is convex and $z(t)$ is concave in t, then this always holds if $k(t)$ is convex.

[18] It cannot yield a tax rate of above one as this would require $-(1 + \left[\frac{\partial k}{\partial t}\right])[n_2 - pn_1(1-z)] - kn_1[p\left[\frac{\partial z}{\partial t}\right] - (1-z)\left[\frac{\partial p}{\partial t}\right]] \geq 0$. The cannot hold as both terms are always negative.

[19] Assume there are no relevant cultural differences between the jurisdictions as they are part of the same federation; however in a study of robberies in California, Japan and the United Kingdom Wolpin (1980) found there were differences.

for either jurisdiction. We assume both the rich's and poor's locational preferences are evenly distributed along $[0, 1]$. Although the anti-crime measure is determined at the federal level each jurisdiction is able to determine the extent to which it is funded. This rules out competition in crime reduction methodologies but allows there to be competition in funding (which is analogous to the system in England and Wales). It also excludes competition in sentencing policy should a criminal be caught and convicted. The funding decision means the domestic jurisdiction is able to levy a tax of t on the rich to fund the anti-crime measure whilst the foreign jurisdiction levies t^*. Assume criminals can only commit a crime in the jurisdiction they choose to reside in. Finally the requirement to maintain a balanced budget is imposed on local jurisdictions as well as the federal government.

Individuals are utility maximising, basing their choice of residence after comparing the utility to be gained from living in either jurisdiction. Thus individuals settle between the two jurisdictions according to

$$s(c, c^*) = \{x \in [0, 1] : u_i(c, c^*, x) \geq u_i^*(c, c^*, x)(i = 1, 2)\}$$

$$s^*(c, c^*) = \{x \in [0, 1] : u_i(c, c^*, x) < u_i^*(c, c^*, x)(i = 1, 2)\}$$

where an asterisk denotes the foreign jurisdiction (Hindriks (1999)). The jurisdictions compete in taxes in order to attract the rich (the mobile capital) and repel the poor (the criminals). Allowing both groups to be mobile between the two jurisdictions causes this paper to differ from the existing literature.

The most relevant existing study is Marceau (1997). He assumes one of the groups is split between the two locations and is unable to move between them whilst the other is able to move freely between the two jurisdictions. The movement of one of the groups allows the jurisdictions to engage in expenditure competition to try to deter criminals from operating in their jurisdiction (in order to repel criminals or attract the capital); one jurisdiction's expenditure has a spillover effect on the other jurisdiction as it causes people to move between the jurisdictions. Whilst Wildasin (1988) reports competition between two jurisdictions in taxes and competition in expenditure leads to different equilibrium outcomes, there is also a

difference in this model due to both groups being mobile. In this tax competition game, a pure strategy Nash equilibrium is characterised as the tax rate at which no individual desires to migrate and no jurisdiction desires to change its tax rate given the policies of its neighbour. Hence a policy outcome $(\hat{c}, \hat{c}^*)$ is a pure strategy Nash equilibrium in taxes iff $\hat{c} = r(s(\hat{c}, \hat{c}^*)|t^*)$ with $\hat{c} \in C(s(\hat{c}, \hat{c}^*))$ and $\hat{c}^* = r(s^*(\hat{c}, \hat{c}^*)|t)$ with $\hat{c}^* \in C(s^*(\hat{c}, \hat{c}^*))$ (Hindriks (1999)).

The decision rule r is common to both jurisdictions, either for electoral reasons or it is specified by the federal government. This is the rule that the jurisdiction's leaders have to fulfil when determining their tax rate – the objective function to be maximised through their choice of tax rate. The decision rule used is for each jurisdiction to maximise the expected income of the rich. If the government of each jurisdiction is seeking re-election then they need only be concerned with the utility of the rich as $n_2 > n_1$. Although their utility also includes a locational element, this is an idiosyncratic element which a jurisdiction's government is unable to influence. In a symmetric equilibrium where both governments levy the same tax which funds identical anti-crime production functions, every individual will reside in the jurisdiction they prefer and therefore local government need only concern itself with maximising expected income. This decision rule is consistent with the previous section and is easily measurable for the jurisdiction's leaders. The next section considers including the locational element in the objective function.

The utility functions of the rich are similar to those in section 2.2 but with the addition of a locational preference. This is represented by $-d_2 x$ for the domestic jurisdiction and $-d_2(1-x)$ for the foreign jurisdiction. d_2 is the attachment to home measure of the rich; a decrease in d_2 represents the rich becoming more mobile. The model assumes d_2 is sufficiently large for both jurisdictions to be evenly populated at an equilibrium. Assume there is no government so all poor people commit crime. Assume half the criminals reside in each jurisdiction and that they are immobile between jurisdictions. In order for there to be an interior solution to the residency decision for the rich

$$1 - \frac{pn_1}{2n_2x_2} - d_2x_2 = 1 - \frac{pn_1}{2n_2(1-x_2)} - d_2(1-x_2)$$

must hold for $0 < x_2 < 1$. This simply states one rich individual must be indifferent between living in either jurisdiction. Thus in order for $x_2 = \frac{1}{2}$ to be an equilibrium, an individual with locational preference $\frac{1}{2} + \delta$ (where δ is very small so the preference for the foreign jurisdiction is weak) must obtain a greater utility from living in the foreign jurisdiction than they could gain by moving jurisdiction, or

$$1 - \frac{pn_1}{2n_2\left(\frac{1}{2}+\delta\right)} - d_2\left(\frac{1}{2}+\delta\right) < 1 - \frac{pn_1}{n_2} - d_2\left(\frac{1}{2}-\delta\right)$$

which reduces to $\frac{pn_1}{n_2(1+2\delta)} < d_2$. As δ approaches zero the requirement for there to be a symmetric equilibrium becomes $d_2 > \frac{pn_1}{n_2}$. If d_2 is too small then the increase in security experienced from decreasing the probability they are a victim of crime, given there is one additional potential victim but no change in the number of criminals, is greater than their attachment to the foreign jurisdiction causing them to leave. This decreases the security of the remaining rich in the foreign jurisdiction and could cause some of them also to leave. If d_2 is sufficiently low then there could be complete depopulation of rich individuals from one jurisdiction leaving it wholly to the remaining poor. Note that the same conditions apply to prevent people in the domestic jurisdiction migrating to the foreign jurisdiction. Thus this model excludes perfect mobility. If the rich were perfectly mobile ($d_2 = 0$) and then they would all reside in the same jurisdiction. In order to attract them, the jurisdiction would have no choice but to levy the tax rate that maximised their expected income given the number of poor who reside there (or, if mobile, migrate there). In this model both the rich and the poor are partially mobile and therefore their migration responses to any change in the tax rates have to bee accounted for when jurisdictions determine taxes.

If the poor are also mobile then their attachment to home measure, d_1, can play a similar role in their residency decision. The greater the attachment to home the less emphasis is placed on income in the residency decision. Again, therefore, the measure needs to be sufficiently high for there to be an interior solution for x_1. In the simple model above where government is absent, a poor person will only consider leaving their preferred jurisdiction if there were no rich individuals to steal from. However when there is a government able to tax and fund a

policing service there are advantages to grouping as it becomes less likely they will be caught. Thus the movement of this group is also dependent on the movement of the rich as this also determines the extent to which an anti-crime measure is funded. (Similarly the movement of the poor will influence the movement of the rich to minimise the probability they become a victim of crime). It is assumed the authorities are not able to observe who migrates in response to a change in the tax rate; only criminals would respond by leaving a jurisdiction if the funding of the police force was altered as the honest poor, those with no intention of committing a crime will maximise utility and remain in the jurisdiction they prefer. As such implicit in the model is that each poor person has a propensity to commit crime which the authorities are unable to observe. Given the law of large numbers the propensity to commit crime becomes the probability any poor person is a criminal.

Little is known about the relationship between d_1 and d_2. It is possible to speculate that d_1 is high, either because the poor have little ability to move jurisdiction, they possess better knowledge of their preferred jurisdiction when committing crime or because gangs can view their homeground as being important (as it confers rights to control the local drug tarde and other benefits). Alternatively it is possible to speculate that d_1 is low as criminals need to be able to move on when the police or other gangs come after them necessitating an ability to move on at short notice. It appears both of these phenomena (low and high d_1s) are occurring simultaneously in the United States at the moment; the fierce battles between gangs in Los Angeles to control the narcotics trade are causing some gangs to flee the cities and migrate to mid-western towns where they displace the existing trade and forces it to move on. Likewise it is possible to speculate that d_2 can be either high (their dividend is dependent on them living in the jurisdiction) or low (they have the money to be able to move jurisdiction and skills to obtain their dividend). Thus it is assumed the two attachment to home measures can take on different values.

2.3.1 Transfer payments

If the central government decides to reduce crime by paying transfer payments to the poor, then the equilibrium response for a rich person will be characterised by the marginal individual x_2 who is indifferent between the two jurisdictions, satisfying

$$(1-t)\left[1-\frac{pn_1x_1}{n_2x_2}\right]-d_2x_2=(1-t^*)\left[1-\frac{p^*n_1(1-x_1)}{n_2(1-x_2)}\right]-d_2(1-x_2) \tag{2.10}$$

where $x_1 \equiv x_1(t,t^*)$ and $x_2 \equiv x_2(t,t^*)$.[20] The propensity to commit crime in the domestic jurisdiction is now $p = p\left(\frac{x_2 t}{x_1}\right)$. Equation (2.10) shows the location choice of the rich is influenced by the location decision of the poor; the number of potential criminals living in a jurisdiction influences the probability they become a victim of crime. This in turn implies the propensity to commit crime in the foreign jurisdiction, $p^*\left(\frac{(1-x_2)t^*}{1-x_1}\right)$, is influenced by the tax rate in the domestic jurisdiction. By definition $1-x_1$ and $1-x_2$ are the proportion of poor and rich individuals in the foreign jurisdiction so any alteration in the domestic tax rate will change not only the tax base but also the number of recipients and therefore the effectiveness of the measure.

Differentiating with respect to t and applying symmetry (where $x_1 = x_2 = \frac{1}{2}$ when $t = t^*$) gives the equilibrium migration response of the rich to a change in the domestic tax rate of

$$\left[\frac{\partial x_2}{\partial t}\right]=\frac{n_2-pn_1+n_1(1-t)\left[\frac{\partial p}{\partial t}\right]-4n_1t(1-t)\left[\frac{\partial p}{\partial t}\right]\left[\frac{\partial x_1}{\partial t}\right]+4pn_1(1-t)\left[\frac{\partial x_1}{\partial t}\right]}{4pn_1(1-t)-4n_1t(1-t)\left[\frac{\partial p}{\partial t}\right]-2n_2d_2} \tag{2.11}$$

where $\left[\frac{\partial p}{\partial t}\right]=\left[\frac{\partial p(t)}{\partial t}\right]$; this is the partial derivative of the propensity to commit crime function with respect to t treating x_1 and x_2 as being fixed at one half. The denominator must be negative in order for a symmetric equilibrium to exist. The first two terms represent the increase in security that a person in the foreign jurisdiction with the lowest value of x would gain if they moved to the domestic jurisdiction. The first term comes from the lower probability of being a victim of crime resulting from an additional rich person, given a fixed number of criminals. The second term is the decrease in the propensity to commit crime resulting from an additional taxpayer increasing the tax yield (which increases the benefit paid if the number

[20] Throughout this section, $x_1(t,t^*)$ is represented by x_1 and $x_2(t,t^*)$ by x_2.

of poor is fixed thus removing the need for some of them to steal). The final term represents the loss in utility stemming from moving to a jurisdiction that is preferred less. Therefore in order for there to be an interior solution for x_2, $2pn_1(1-t) - 2n_1t(1-t)\left[\frac{\partial p}{\partial t}\right] - n_2d_2 < 0$ (the loss in locational utility is greater than the increased security if they moved). Thus (2.11) is decreasing in magnitude in d_2; as the rich become more mobile their equilibrium migration response increases. As mentioned before the movement of poor impact in the movement if the rich in response to a change in the domestic tax rate. Unsurprisingly the equilibrium migration response of the rich responds negatively to the equilibrium migration response of the poor.

The equilibrium response of a poor person will be characterised by the marginal individual x_1 who is indifferent between the jurisdictions, meaning

$$p(1-t) + \frac{tn_2x_2}{n_1x_1} - d_1x_1 = p^*(1-t^*) + \frac{t^*n_2(1-x_2)}{n_1(1-x_1)} - d_1(1-x_1). \tag{2.12}$$

Although p takes on the values of either 0 or 1 (depending on whether or not an individual is a criminal), the government of a jurisdiction does not know whether the marginal poor person is a criminal or not and can only base their decision on the expected migration response. Differentiating (2.12) with respect to t and applying symmetry in the same way as before leads to an equilibrium migration response of the poor to a change in the domestic tax rate of

$$\left[\frac{\partial x_1}{\partial t}\right] = \frac{n_2 - pn_1 + n_1(1-t)\left[\frac{\partial p}{\partial t}\right] + 4n_1t(1-t)\left[\frac{\partial p}{\partial t}\right]\left[\frac{\partial x_2}{\partial t}\right] + 4n_2t\left[\frac{\partial x_2}{\partial t}\right]}{4n_1t(1-t)\left[\frac{\partial p}{\partial t}\right] + 4n_2t + 2n_1d_1} \tag{2.13}$$

In just the same way as the movement of the poor impacts on the movement of the rich, the equilibrium migration response of the poor is dependent on the equilibrium migration response of the rich. The denominator has to be positive if there is an interior solution for the poor.[21] The first term represents the change in the return from crime whilst the second represents the change to the benefit level. The final term represents the change in utility stemming from moving to the jurisdiction they prefer less. Whilst the response to the migration response of the rich is ambiguous (higher benefits compared to lower returns from crime), the equilibrium

[21]Strictly speaking the denominator, when multiplied by -1 needs to be negative.

migration response of the poor is decreasing in magnitude in d_1; as they become less mobile the migration response decreases in magnitude.

The decision rule the local governments have to follow is to maximise the expected income of its rich inhabitants, so the domestic jurisdiction aims to $\max(1-t)\left[1-\frac{pn_1x_1}{n_2x_2}\right]$ with respect to t (remembering $x_1 = x_1(t, t^*)$ and $x_2 = x_1(t, t^*)$). The trade-off faced by the rich is between increased post tax income and increased security for the post tax income. Given the presence of x_1 and x_2, p being convex in t is no longer sufficient to ensure the equilibrium tax rate maximises utility. However assume the specification of p ensures the expected income of the rich is concave in t. Due to the symmetry, the tax rate that maximises the expected income of the rich inhabitants in the domestic jurisdiction will also be the tax rate that maximises the expected income if the inhabitants of the foreign jurisdiction at the equilibrium.

Proposition 1 *In a two jurisdictional economy where the jurisdictions are free to compete in taxes to fund transfer payments as an anti-crime measure, there exists a pure strategy Nash equilibrium tax rate which solves*

$$t = \frac{n_1\left[\frac{\partial p}{\partial t}\right] + n_2 - pn_1 - 2n_2d_2\left[\frac{\partial x_2}{\partial t}\right]}{n_1\left[\frac{\partial p}{\partial t}\right]}.$$

If $0 \leq t \leq 1$ *then both jurisdictions will levy a tax of* t*. Otherwise the jurisdictions will charge 0 if* $t < 0$ *whilst they will charge 1 if* $t > 1$*.*

Proposition one states that a Nash equilibrium in taxes exists. The form of the interior Nash equilibrium tax rate is similar to the tax rate levied by a single jurisdiction, however with the addition of a term dependent upon the equilibrium migration response of the rich. If the migration response of the rich to a change in the domestic tax rate at the equilibrium is positive then the Nash equilibrium tax rate will be higher than optimal. If the migration response of the rich to a change in the domestic tax rate at the equilibrium is negative then the Nash equilibrium tax rate will be lower than optimal. Thus the effect of tax competition is to distort taxes away from the optimum.

It is interesting to note the role the attachment to home measure of the rich plays. Although excluded if there is to be a symmetric equilibrium, if the rich are perfectly mobile (so $d_2 = 0$)

the resulting Nash equilibrium tax is the optimal tax. If $d_2 > 0$, so the rich are imperfectly mobile, in the majority of cases a non-optimal tax will be levied (the exception being if $\left[\frac{\partial x_2}{\partial t}\right] = 0$). Whilst the effect of the distortion on the equilibrium tax is increasing in d_2, the attachment to home measure of the rich is decreasing in d_2. As the properties of the tax in relation to d_2 is not transparent a numerical example is used to demonstrate the properties the equilibrium tax can have; a more detailed examination of this issue is in the next chapter. Assume $n_1 = 800$, $n_2 = 1000$ and $p = 1 - \frac{4}{5}B = 1 - \frac{x_2 t}{x_1}$. The optimum tax to maximise the expected income of the rich is 0.375. If d_1 is fixed at 0.22 then by increasing d_2 from 0.08 to 0.12 one of the equilibrium tax rate decreases from 0.431 to 0.234. Thus as the rich become more mobile the equilibrium tax decreases and can move away from the optimum. For comparison if $d_2 = 0.1$ then one of the equilibrium tax increases from 0.246 to 0.337 if d_1 increases from 0.18 to 0.22. There is, however, a second equilibrium tax.

Corollary 2 *When transfer payments are used as an anti-crime measure and both the rich and the poor individuals are risk neutral, the tax rate that would be levied in a one jurisdictional economy is a pure strategy Nash equilibrium in a two jurisdictional economy.*

The proof follows from rewriting the equilibrium migration responses of the rich as $x_1' = \frac{\alpha_0+\alpha_1 x_2'}{\alpha_1+\alpha_2}$ and $x_2' = \frac{\alpha_0+\alpha_3 x_1'}{\alpha_3+\alpha_4}$ where $\alpha_0 = n_2 - pn_1 + p'n_1(1-T)$, $\alpha_1 = 4p'n_1T(1-T) + 4n_2T$, $\alpha_2 = 2n_1d_1$, $\alpha_3 = 4pn_1(1-T) - 4p'n_1T(1-T)$ and $\alpha_4 = -2n_2d_2$. From proposition six the Nash equilibrium tax rate solves $\alpha_0 + \alpha_4 x_2' = 0$. Solving for x_2' gives $x_2' = \frac{\alpha_0(\alpha_1+\alpha_2+\alpha_3)}{\alpha_1\alpha_4+\alpha_2(\alpha_3+\alpha_4)}$. Substituting this into the expression for the Nash equilibrium and rearranging gives $\frac{\alpha_0[2\alpha_4(\alpha_1+\alpha_2)+\alpha_3(\alpha_2+\alpha_4)]}{\alpha_1\alpha_4+\alpha_2(\alpha_3+\alpha_4)} = 0$. The tax rate that solves $\alpha_0 = 0$ is $T = \frac{n_1\left[\frac{\delta p}{\delta T}\right]+n_2-pn_1}{n_1\left[\frac{\delta p}{\delta T}\right]}$ which is the same tax rate as for the single jurisdiction. Thus the tax levied optimally when there is one jurisdiction causes the equilibrium migration response of both the rich and the poor to be exactly equal to zero leading to neither jurisdiction having any incentive to deviate from this. The implication of this corollary is that tax competition need not introduce any distortions to tax rates. If the service starts being provided by the federal government and is then devolved to local government there need not be any change in the tax rate charged.

In the discussion on transfer payments in a single jurisdiction it was mentioned that they acted in a similar manner to the prevention role policing can have. Increasing the tax rate results in more police on the streets presenting fewer opportunities for criminals to commit crime. However this modeling no longer holds true in a two jurisdiction world as the utility functions of the poor are now misspecified. Let $p\left(\frac{x_2 t}{x_1}\right)$ be the propensity to commit crime in the single jurisdiction when the tax receipts fund visible policing. Whilst (2.10) and (2.11) still hold for the rich individuals the equilibrium poor person will be characterised by the marginal individual x_1 who is indifferent between the jurisdictions according to

$$p(1-t) - d_1 x_1 = p^*(1-t^*) - d_1(1-x_1) \tag{2.14}$$

meaning the equilibrium migration response of the poor to a change in the domestic tax rate is given by

$$\left[\frac{\partial x_1}{\partial t}\right] = \frac{(1-t)(1+4t\left[\frac{\partial x_2}{\partial t}\right])\left[\frac{\partial p}{\partial t}\right] - p}{2d_1 + 4t(1-t)\left[\frac{\partial p}{\partial t}\right]} \tag{2.15}$$

Whilst proposition one still applies for the pure strategy Nash equilibrium tax, the equilibrium migration response of the poor is now given by (2.11) whilst the equilibrium migration response of the rich is still given by (2.15). The consequence of this is that the collarary, when the tax receipts are used to find visible policing, no longer applies. Whilst the equilibrium migration response of the rich remains $x_2' = \frac{\alpha_0 + \alpha_3 x_1'}{\alpha_3 + \alpha_4}$ the equilibrium migration response of the poor is now $x_1' = \frac{\widehat{\alpha_0} + \alpha_1 x_2'}{\alpha_1 + \alpha_2}$ meaning the optimal tax rate now solves $\alpha_0 + \frac{\alpha_4(\alpha_0\alpha_1 + \alpha_0\alpha_2 + \widehat{\alpha_0}\alpha_3)}{\alpha_1\alpha_4 + \alpha_2\alpha_3 + \alpha_2\alpha_4} = 0$; α_0 is no longer a solution. Although the payment of benefits as an anti-crime measure can be devolved to local governments without any affect on the tax rate levied, devolving tax raising powers to provide visible policing will, most likely, result in distorted taxes being levied.

2.3.2 Fines related to the amount stolen

If both jurisdictions now punish by using fines related to the amount stolen, then the equilibrium response for a rich person will be characterised by the marginal individual x_2 who is indifferent between the jurisdictions satisfying

$$(1-t)\left[1-(1-hz)\frac{pn_1x_1}{n_2x_2}\right] - d_2x_2 = (1-t^*)\left[1-(1-hz^*)\frac{p^*n_1(1-x_1)}{n_2(1-x_2)}\right] - d_2(1-x_2) \tag{2.16}$$

The propensity to commit crime is assumed to be the amount spent per crime, $p\left(\frac{x_2 t}{x_1}\right)$, meaning the probability of detection is $z\left(\frac{x_2 t}{x_1}\right)$ in the domestic jurisdiction. Differentiating with respect to t and applying symmetry to find the migration response of the rich to a change in the domestic tax rate at the equilibrium yields

$$\left[\frac{\partial x_2}{\partial t}\right] = \frac{-n_2 + pn_1(1-hz) - n_1(1-t)\{(4t\left[\frac{\partial x_1}{\partial t}\right] - 1)[ph\left[\frac{\partial z}{\partial t}\right] - (1-hz)\left[\frac{\partial p}{\partial t}\right]] + 4p(1-hz)\left[\frac{\partial x}{\partial t}\right.}{2n_2 d_2 - 4n_1(1-t)\{t[p\left[\frac{\partial z}{\partial t}\right] - (1-hz)\left[\frac{\partial p}{\partial t}\right] + p(1-hz)]\}} \tag{2.17}$$

where $\left[\frac{\partial z}{\partial t}\right] = \left[\frac{\partial z(t)}{\partial t}\right]$ keeping $x_1 = x_2 = \frac{1}{2}$. As before the denominator has to be positive if there is to be a symmetric equilibrium (otherwise the gains of increased security outweigh the disutility from living in a jurisdiction that is preferred less). Thus the equilibrium migration response of the rich is decreasing in magnitude in their attachment to home measure. Further the interactions between the two groups means the movement of the rich depends on the movement of the poor. This will always have a negative relationship if $1 > hz$ or the expected compensation is less than the amount stolen.

The equilibrium response for a poor person will be characterised by the marginal individual x_1 who is indifferent between the jurisdictions, satisfying

$$p(1-t)(1-hz) - d_1 x_1 = p^*(1-t^*)(1-hz^*) - d_1(1-x_1). \tag{2.18}$$

Differentiating with respect to t and applying symmetry gives an equilibrium migration response to a change in the domestic tax of

$$\left[\frac{\partial x_1}{\partial t}\right] = \frac{-p(1-hz) + (1-t)(4t\left[\frac{\partial x_2}{\partial t}\right] + 1)[(1-hz)\left[\frac{\partial p}{\partial t}\right] - ph\left[\frac{\partial z}{\partial t}\right]]}{2d_1 + 4t(1-t)[(1-hz)\left[\frac{\partial p}{\partial t}\right] - ph\left[\frac{\partial z}{\partial t}\right]]}. \tag{2.19}$$

The denominator has to be positive in order for the poor to reside in both jurisdictions at the equilibrium. Again the interdependence between the two groups is present. If $\left[\frac{\partial x_2}{\partial t}\right] > 0$ and $1 > hz$ then the response will be negative; the increase in the tax rate attracts the rich lowering the return from crime causing the poor to leave. However under other circumstances the direction of the equilibrium migration response of the poor is ambiguous.

The decision rule of the local government is to maximise the expected income if its rich inhabitants, $\max(1-t)\left[1-(1-hz)\frac{pn_1x_1}{n_2x_2}\right]$ with respect to t gives rise to the equilibrium tax

rate. Again assume that the specifications of p and z ensure the expected income is concave in t.

Proposition 3 *In a two jurisdictional economy where the jurisdictions are free to compete in taxes to fund a police force (where the sanction imposed on criminals, if caught, is a fine related to the amount stolen), there exists a pure strategy Nash equilibrium tax rate which solves*

$$t = \frac{n_1[ph\left[\frac{\partial z}{\partial t}\right] - (1-hz)\left[\frac{\partial p}{\partial t}\right]] - n_1 + pn_1(1-hz) + 2n_2d_2\left[\frac{\partial x_2}{\partial t}\right]}{ph\left[\frac{\partial z}{\partial t}\right] - (1-hz)\left[\frac{\partial p}{\partial t}\right]}.$$

If $0 \leq t \leq 1$ *then both jurisdictions will levy a tax of* t*. Otherwise the jurisdictions will charge 0 if* $t < 0$ *whilst they will charge 1 if* $t > 1$*.*

A pure strategy Nash equilibrium exists that possesses a similar structure to the optimal tax for a single jurisdiction. As for transfer payments the equilibrium tax is distorted by the equilibrium migration response of the rich to a change in the domestic tax rate. If the migration response of the rich to a change in the domestic tax at the equilibrium is positive then the equilibrium tax will be higher than optimal. Conversely if the migration response of the rich to a change in the domestic tax rate at the equilibrium is negative then the equilibrium tax will be lower than optimum. The role of the attachment to home measure of the rich remains ambiguous. Whilst the effect of the distortion in the equilibrium tax is increasing the equilibrium migration response of the rich is decreasing in the attachment to home measure. However there is no corollary stating the optimal tax rate is a pure strategy Nash equilibrium.[22] If the rich are imperfectly mobile then unless $\left[\frac{\partial x_2}{\partial t}\right] = 0$ the outcome is for a distorted tax to be levied if the tax raising powers are devolved to local government.

2.3.3 Fines unrelated to the amount stolen

Assume both jurisdictions punish by means of a punitive fine. For the domestic jurisdiction the police production function can be written as $z\left(\frac{x_2 t}{x_1}\right)$ and the propensity to commit crime function can be written as $p\left(\frac{x_2 t}{x_1}, f\right) = p\left(\frac{x_2 t}{x_1}\right)$ since the fine is determined at the federal level

[22]The equilibrium migration responses of the poor and the rich can be written as $x_1 = \frac{\alpha_0+\alpha_1 x_2'}{\alpha_1+\alpha_2}$ and $x_2 = \frac{\beta_0+\beta_1 x_1'}{\beta_1+\beta_2}$. Solving for x_2 gives $x_2 = \frac{\alpha_0\beta_1+\alpha_1\beta_0+\alpha_2\beta_0}{\alpha_1\beta_2+\alpha_2\beta_1+\alpha_2\beta_2}$. Substituting this into the expression for the Nash equilibrium tax gives $0 = \beta_0 + \beta_2 x_2'$ or $0 = \frac{2\beta_0\beta_2(\alpha_1+\alpha_2)+\beta_1(\alpha_0\beta_2+\alpha_2\beta_0)}{\alpha_1\beta_2+\alpha_2\beta_1+\alpha_2\beta_2}$. Unlike for transfers where $\alpha_0 = \beta_0$ here β_0 is not a factor and therefore the optimal tax (with no migration) is not a Nash equilibrium tax.

and thus a variable outside the control of local government. The equilibrium response of a rich person will be characterised by the marginal individual x_2 who is indifferent between the jurisdictions satisfying

$$(1-t)\left[1-\frac{pn_1x_1}{n_2x_2}\right]+\frac{pn_1x_1}{n_2x_2}zqf-d_2x_2=(1-t^*)\left[1-\frac{p^*n_1(1-x_1)}{n_2(1-x_2)}\right]+\frac{pn_1(1-x_1)}{n_2(1-x_2)}zqf-d_2(1-x_2). \tag{2.20}$$

Differentiating with respect to t to find the migration response of the rich to a change in the domestic tax rate and applying symmetry yields

$$\left[\frac{\partial x_2}{\partial t}\right]=\frac{-n_2+pn_1+n_1(1-t-zqf)[(4t\left[\frac{\partial x_1}{\partial t}\right]-1)\left[\frac{\partial p}{\partial t}\right]-4p\left[\frac{\partial x_1}{\partial t}\right]]-pn_1qf(4t\left[\frac{\partial x_1}{\partial t}\right]-1)\left[\frac{\partial z}{\partial t}\right]}{2n_2d_2+4n_1(1-t-zqf)[t\left[\frac{\partial p}{\partial t}\right]-4tpn_1qf\left[\frac{\partial z}{\partial t}\right]]} \tag{2.21}$$

The denominator has to be positive if there is to be a symmetric equilibrium meaning the equilibrium migration response of the rich is decreasing in magnitude in their attachment to home. Their response is also dependent on the migration response of the poor as the tax increase reduces the return from crime and therefore influences their movement. If the expected compensation is small then the rich respond negatively to the migration response of the poor.

The equilibrium response for a poor person will be characterised by the marginal individual x_1 who is indifferent between the jurisdictions satisfying

$$p(1-t)-pzqf-d_1x_1=p^*(1-t^*)-p^*z^*qf-d_1(1-x_1). \tag{2.22}$$

Hence the equilibrium migration response of the poor to a change in the domestic tax is given by (applying symmetry where $x_1=x_2=\frac{1}{2}$, $t=t^*$)

$$\left[\frac{\partial x_1}{\partial t}\right]=\frac{(1+4t\left[\frac{\partial x_2}{\partial t}\right])[(1-t)\left[\frac{\partial p}{\partial t}\right]-qf(z\left[\frac{\partial p}{\partial t}\right]+p\left[\frac{\partial z}{\partial t}\right])]}{2d_1+4t[(1-t)\left[\frac{\partial p}{\partial t}\right]-qf(z\left[\frac{\partial p}{\partial t}\right]+p\left[\frac{\partial z}{\partial t}\right])]}. \tag{2.23}$$

The equilibrium response of the poor to a change in the domestic tax rate is ambiguous. The denominator has to be positive if there is to be a symmetric equilibrium so the equilibrium migration response is decreasing in magnitude in d_1. However the numerator can be either negative or positive depending on the equilibrium migration response of the rich and whether the propensity to commit crime or detection dominates at the margin. Recall the aim of each

jurisdiction is to maximise the income of the rich, $\max(1-t)\left[1-\frac{pn_1x_1}{n_2x_2}\right]+\frac{pn_1x_1}{n_2x_2}zqf$, with respect to the domestic tax, t. Assume expected income is concave in t.

Proposition 4 *In a two jurisdictional economy where the jurisdictions are free to compete in taxes to fund a police force (where the sanction imposed on criminals, if caught, is a fine unrelated to the amount stolen), there exists a pure strategy Nash equilibrium tax rate which solves*

$$t=\frac{n_2-pn_1+n_1\left[\frac{\partial p}{\partial t}\right]-n_1qf(p\left[\frac{\partial z}{\partial t}\right]+z\left[\frac{\partial p}{\partial t}\right])-2n_2d_2\left[\frac{\partial x_2}{\partial t}\right]}{n_1\left[\frac{\partial p}{\partial t}\right]}$$

If $0\leq t\leq 1$ *then both jurisdictions will levy a tax of* t*. Otherwise the jurisdictions will charge 0 if* $t<0$ *whilst they will charge 1 if* $t>1$*.*

Changing the type of fine imposed does not alter the structure of the equilibrium tax. The equilibrium tax is distorted from the optimum tax by the equilibrium migration response of the rich to a change in the domestic tax rate. Further the direction away from the optimum is the same as the direction of the equilibrium migration response of the rich. Again there is ambiguity in the role the attachment to home measure of the rich plays. Changing the sanction imposed on a criminal, if caught, does not alter the effect devolving tax raising powers to fund anti-crime measures has.

2.3.4 Incarceration

The final method of punishment the federal government can choose to impose is incarceration. The equilibrium migration response of a rich individual will be characterised by the marginal individual x_2 who is indifferent between jurisdictions satisfying

$$\left(1-t-\frac{k}{x_2}\right)\left[1-\frac{px_1n_1(1-z)}{n_2x_2}\right]-d_2x_2$$

$$=\left(1-t^*-\frac{k^*}{1-x_2}\right)\left[1-\frac{p^*(1-x_1)n_1(1-z^*)}{n_2(1-x_2)}\right]-d_2(1-x_2) \qquad (2.24)$$

where $k=k\left(\frac{x_2t}{2x_1}\right)$. This model assumes responsibility for funding the sanction is also devolved to the local jurisdiction (preventing a jurisdiction free-riding on the other's federal tax receipts to fund their more productive police force). Accordingly if the total cost of the domestic prison is k then the jurisdiction's x_2 rich residents have to pay $\frac{k}{x_2}$ for it. The presence of the 2 in k

reflects a given tax rate only catching half the number of criminals compared to the federal system. This model can be viewed as the stage game of a repeated game; at the start of the period a number of people are in prison who will be released at the end of the period only to be replaced by the same number of new criminals caught and convicted. The equilibrium migration response of a rich individual, calculated in the usual manner, is

$$\left[\frac{\partial x_2}{\partial t}\right] = \frac{-(1+\left[\frac{\partial k}{\partial t}\right]-4t\left[\frac{\partial k}{\partial t}\right]\left[\frac{\partial x_1}{\partial t}\right])A+n_1(1-t-k)[(4t\left[\frac{\partial x_1}{\partial t}\right]-1)B-4p(1-z)\left[\frac{\partial x_1}{\partial t}\right]]}{2n_2d_2+4(t\left[\frac{\partial k}{\partial t}\right]-2k)A+n_1(1-t-k)[4tB-4p(1-z)]} \tag{2.25}$$

where $A = n_2 - pn_1(1-z)$ and $B = (1-z)\left[\frac{\partial p}{\partial t}\right] - p\left[\frac{\partial z}{\partial t}\right]$. As usual the denominator is increasing in d_2 (in order for a symmetric equilibrium to exist) so as the group becomes less mobile, the equilibrium migration response falls in magnitude. The usual interdependency between the two groups is also present.

The equilibrium response of a poor person will be characterised by the marginal individual x_1, who is indifferent between jurisdictions, satisfying

$$p(1-z)\left(1-t-\frac{k}{x_2}\right)-pzv-d_1x_1 = p^*(1-z^*)\left(1-t^*-\frac{k^*}{1-x_2}\right)-p^*z^*v-d_1(1-x_1) \tag{2.26}$$

where v is the disutility associated with being caught and thrown in prison – this value is assumed to be the same for all criminals. Hence the migration response of a poor person to an increase in the domestic tax rate, calculated in the usual way, is

$$\left[\frac{\partial x_1}{\partial t}\right] = \frac{C(1+4t\left[\frac{\partial x_2}{\partial t}\right])-p(1-z)(1+8k\left[\frac{\partial x_2}{\partial t}\right])}{2d_1+4tC} \tag{2.27}$$

where $C = (1-z)(1-t-k)\left[\frac{\partial p}{\partial t}\right] - p(1-t-k)\left[\frac{\partial z}{\partial t}\right] - p(1-z)\left[\frac{\partial k}{\partial t}\right] - zv\left[\frac{\partial p}{\partial t}\right] - pv\left[\frac{\partial z}{\partial t}\right]$. This follows the same form as the other equilibrium migration responses of the poor to a change in the domestic tax rate. As the poor become more mobile the equilibrium migration response increases in magnitude, however the direction is influence by the movement of the rich.

The domestic jurisdiction, seeking to maximise the utility of its rich residents, will maximise their non-locational utility. Assume this is concave in t. The pure strategy Nash equilibrium, given the movement of both capital and criminals in a symmetric world, is the tax rate that

solves

$$t = \frac{-(1 + \left[\frac{\partial k}{\partial t}\right])[n_2 - pn_1(1-z)] + (1-k)[pn_1\left[\frac{\partial z}{\partial t}\right] + n_1(1-z)\left[\frac{\partial p}{\partial t}\right]] + 2n_2 d_2\left[\frac{\partial x_2}{\partial t}\right]}{pn_1\left[\frac{\partial z}{\partial t}\right] - n_1(1-z)\left[\frac{\partial p}{\partial t}\right]}. \quad (2.28)$$

Changing the anti-crime measure to imprisonment does not alter the structure of the tax in a two jurisdiction world; the optimal tax for a single jurisdiction is distorted by the presence of the equilibrium migration response of the poor. However as the equilibrium migration response of the rich is dependent on the equilibrium migration response of the poor the resulting tax rate is now directly affected by the sanction imposed. In a single jurisdictional world the severity of the sanction only impacts on p, the participation in crime decision. Whilst this remains the case in a two jurisdiction world, the sanction is included in the equilibrium migration response of the poor and therefore directly influences the resulting tax. This feature will be returned to in the next chapter.

Proposition 5 *In a two jurisdictional economy which uses incarceration as its anti-crime measure and competes in taxes, the pure strategy Nash equilibrium is the tax rate which solves*

$$t = \frac{-(1 + \left[\frac{\partial k}{\partial t}\right])[n_2 - pn_1(1-z)] + (1-k)[pn_1\left[\frac{\partial z}{\partial t}\right] + n_1(1-z)\left[\frac{\partial p}{\partial t}\right]] + 2n_2 d_2\left[\frac{\partial x_2}{\partial t}\right]}{pn_1\left[\frac{\partial z}{\partial t}\right] - n_1(1-z)\left[\frac{\partial p}{\partial t}\right]}.$$

If $0 \leq t \leq 1$ *then both jurisdictions will levy a tax of* t*. Otherwise the jurisdictions will charge 0 if* $t < 0$ *whilst it will charge 1 if* $t > 1$*.*

An alternative model would be for taxes for policing to be determined at the local level whilst the federal level funds prisons, as they retain the power to determine the sanction. This is the system that occurs in England and Wales. This changes the cost of prisons charged to each rich individual to $k\left(\frac{x_2 t}{2x_1} + \frac{(1-x_2)t^*}{2(1-x_1)}\right)$. This means the equilibrium migration response of a rich individual becomes

$$\left[\frac{\partial x_2}{\partial t}\right] = \frac{-A + n_1(1-t-k)[(4t\left[\frac{\partial x_1}{\partial t}\right] - 1)B - 4p(1-z)\left[\frac{\partial x_1}{\partial t}\right]]}{2n_2 d_2 + n_1(1-t-k)[4tB - 4p(1-z)]}.$$

This differs from the previous specification as the marginal cost of incarceration disappears; as the cost of incarceration are shared any change due to a change in t cannot be avoided by moving jurisdiction. The k remains as it impacts on post tax income. The equilibrium

migration response of the poor is also altered to

$$\left[\frac{\partial x_1}{\partial t}\right] = \frac{D(1+4t\left[\frac{\partial x_2}{\partial t}\right]) - p(1-z)}{2d_1 + 4tD}$$

where $D = (1-z)(1-t-k)\left[\frac{\partial p}{\partial t}\right] - p(1-t-k)\left[\frac{\partial z}{\partial t}\right] - zv\left[\frac{\partial p}{\partial t}\right] - pv\left[\frac{\partial z}{\partial t}\right]$. Both the equilibrium migration responses have the usual properties, for example they decrease in magnitude in the attachment to home. The pure strategy Nash equilibrium is the tax rate that solves

$$t = \frac{-(1+2\left[\frac{\partial k}{\partial t}\right])[n_2 - pn_1(1-z)] + (1-k)[pn_1\left[\frac{\partial z}{\partial t}\right] + n_1(1-z)\left[\frac{\partial p}{\partial t}\right]] + 2n_2d_2\left[\frac{\partial x_2}{\partial t}\right]}{pn_1\left[\frac{\partial z}{\partial t}\right] - n_1(1-z)\left[\frac{\partial p}{\partial t}\right]}.$$

This follows a similar form to before; the tax is distorted by the equilibrium migration response of the rich. There is also a change to the coefficient in front of $\left[\frac{\partial k}{\partial t}\right]$ stemming from its exclusion from the equilibrium migration response of the rich. Thus devolving the funding for policing but not for prisons can introduce another distortion providing the prisons have to be funded by taxpayers. The next chapter allows a socially costless sanction to be imposed if a criminal is caught and demonstrates the power the federal government holds when it retains the power to determine the sanction.

Thus irrespective of the anti-crime measure deployed by a jurisdiction all the pure strategy Nash equilibrium tax rates follow the same form if the decision rule is to maximise the non-locational utility of the rich. The equilibrium tax rate is the optimal tax rate for a single jurisdiction distorted by $2n_2d_2\left[\frac{\partial x_2}{\partial t}\right]$. Thus the equilibrium tax will be higher than optimal if the equilibrium migration response is positive at the equilibrium whilst the equilibrium tax will be lower than optimal if the equilibrium migration response of the rich is negative at the equilibrium.

2.4 Extensions and policy implications

The preceding section gives a series of equations detailing the pure strategy Nash equilibrium tax rates. This section relaxes some of the assumptions underlying these results and pull together some of the theoretical results in an attempt to infer some policy conclusions from them. Throughout this section the anti-crime measure considered is fines related to the

amount stolen though the key result, tax competition distorting the equilibrium taxes by the equilibrium migration response of the rich, was common to all the specifications.

2.4.1 Functional forms of the production functions

In section 4 the production function depended on the amount spent per poor person in a jurisdiction. This is restrictive as the relevant variable could be the total funds allocated to the police or some other functional form. Therefore now assume both the propensity to commit crime and detection are functions of the proportion of rich people in the jurisdiction, the proportion of poor people in the jurisdiction and the tax rate levied. Thus $p(x_1, x_2, t)$ and $p(x_1, x_2, t)$ in the domestic jurisdiction whilst $p^*(-x_1, -x_2, t^*)$ and $z^*(-x_1, -x_2, t^*)$ in the foreign. It is assumed both jurisdictions share the same technology. The equilibrium migration responses of the poor and the rich can now be given by

$$\left[\frac{\partial x_1}{\partial t}\right] = \frac{-p(1-hz) + (1-t)(1-hz)(2\frac{\partial p}{\partial x_2}\frac{\partial x_2}{\partial t} + \frac{\partial p}{\partial t}) - ph(1-t)(2\frac{\partial z}{\partial x_2}\frac{\partial x_2}{\partial t} + \frac{\partial z}{\partial t})}{2d_1 - 2(1-hz)(1-t)\frac{\partial p}{\partial x_1} + 2ph(1-t)\frac{\partial z}{\partial x_1}}$$

and

$$\left[\frac{\partial x_2}{\partial t}\right] = \frac{A + n_1(1-t)[ph(2\frac{\partial z}{\partial x_1}\frac{\partial x_1}{\partial t} + \frac{\partial z}{\partial t}) - (1-hz)(\frac{\partial p}{\partial x_1}\frac{\partial x_1}{\partial t} + \frac{\partial p}{\partial t}) + 4p(1-hz)\frac{\partial x_1}{\partial t}]}{2n_2d_2 - n_1(1-t)[2ph\frac{\partial z}{\partial x_2} - 2(1-hz)\frac{\partial p}{\partial x_2} + 4p(1-hz)]}$$

where $A = -n_2 + pn_1(1-hz)$. The pure strategy Nash equilibrium tax rate, found in the usual way if the jurisdiction aims to maximise the expected income of the rich, is the tax rate that solves

$$t = \frac{n_1[ph\left[\frac{\partial z}{\partial t}\right] - (1-hz)\left[\frac{\partial p}{\partial t}\right]] - n_1 + pn_1(1-hz) + 2n_2d_2\left[\frac{\partial x_2}{\partial t}\right]}{ph\left[\frac{\partial z}{\partial t}\right] - (1-hz)\left[\frac{\partial p}{\partial t}\right]}.$$

Although the equilibrium migration responses change, the structure of the optimal tax remains unaltered meaning the distortion is not due to the production functions employed. This holds across all the models considered, meaning, for example, it might not be the benefit level that determines the participation in crime decision, rather another form of income inequality between the rich and the poor could be the cause.

2.4.2 Decision rules

It has been assumed so far that the aim of each jurisdiction is to maximise the expected income of its rich individuals. This need not necessarily be utility maximising as their utility functions contain not only expected income but also a locational choice parameter. If the decision rule is altered to maximise the expected utility of the rich individual with the least strongest preference for the jurisdiction, $\max(1-t)\left[1-(1-hz)\frac{pn_1x_1}{n_2x_2}\right]-d_2x_2$, then the pure strategy Nash equilibrium tax rates is exactly the same as those derived in section 2.2. If the aim of the jurisdictions is to maximise the expected welfare of its rich inhabitants then a symmetric equilibrium will not induce any distortions in the optimal tax rate. Thus if the federal government imposes this decision rule on local jurisdictions, then the taxes levied will be optimal for the rich inhabitants.

2.4.3 Distortions

In this subsection we allow for there to be a distortion between the amount paid by the rich and the amount spent on the anti-crime measure. Let λ be the distortion where $\lambda \in [0,1)$. Thus for every t paid by a rich individual $(1-\lambda)t$ is spent. The resulting pure strategy Nash equilibrium tax rate for a two jurisdictional economy solves

$$t=\frac{n_1[ph(1-\lambda)\left[\frac{\partial z}{\partial t}\right]-(1-hz)(1-\lambda)\left[\frac{\partial p}{\partial t}\right]]-n_1+pn_1(1-hz)+2n_2d_2\left[\frac{\partial x_2}{\partial t}\right]}{ph(1-\lambda)\left[\frac{\partial z}{\partial t}\right]-(1-hz)(1-\lambda)\left[\frac{\partial p}{\partial t}\right]}$$

where

$$\left[\frac{\partial x_1}{\partial t}\right]=\frac{-p(1-hz)+(1-\lambda)(1-t)(4t\left[\frac{\partial x_2}{\partial t}\right]+1)[(1-hz)\left[\frac{\partial p}{\partial t}\right]-ph\left[\frac{\partial z}{\partial t}\right]]}{2d_1+4t(1-\lambda)(1-t)[(1-hz)\left[\frac{\partial p}{\partial t}\right]-ph\left[\frac{\partial z}{\partial t}\right]]}$$

and

$$\left[\frac{\partial x_2}{\partial t}\right]=\frac{A-n_1(1-\lambda)(1-t)\{(4t\left[\frac{\partial x_1}{\partial t}\right]-1)[ph\left[\frac{\partial z}{\partial t}\right]-(1-hz)\left[\frac{\partial p}{\partial t}\right]]+4p(1-hz)\left[\frac{\partial x_1}{\partial t}\right]\}}{2n_2d_2-4n_1(1-\lambda)(1-t)\{t[p\left[\frac{\partial z}{\partial t}\right]]-(1-hz)\left[\frac{\partial p}{\partial t}\right]+p(1-hz)\}}$$

(and $A=-n_2+pn_1(1-hz)$). The effect of the distortion is to lower both the marginal detection rate and the marginal propensity to commit crime. Although this equates to a lower optimal tax rate it is difficult to tell, due to the non-linearities, what the overall effect

on the equilibrium tax rate is. However an increase in efficiency will increase the underlying tax and result in increased resources for the police.

2.4.4 Attitude towards risk

In the preceding analysis it has been assumed that both the poor and rich are risk neutral. In this subsection we alter this assumption to allow the rich to be risk averse. Further it is assumed they possess constant relative risk aversion in the utility money provides. To simplify matters assume $h = 1$, so if caught a criminal repays the amount stolen. The utility of a rich individual is now given by $u_2 = \frac{(1-t)^{1-\alpha}}{1-\alpha}\left[1-(1-z)\frac{pn_1}{n_2}\right]$. This ensures utility is now concave in wealth. The tax rate that maximises the non-locational utility of the rich is

$$t = \frac{-(1-\alpha)[n_2 - pn_1(1-z)] + n_1[p\left[\frac{\partial z}{\partial t}\right] - (1-z)\left[\frac{\partial p}{\partial t}\right]]}{n_1[p\left[\frac{\partial z}{\partial t}\right] - (1-z)\left[\frac{\partial p}{\partial t}\right]]}$$

As would be expected the tax rate that maximises expected income is lower than the non-locational utility maximising tax rate. Further the more risk averse individuals are, the higher the tax they are prepared to pay. In a two jurisdictional world the equilibrium migration response of the rich to a change in the domestic tax rate is given by

$$\left[\frac{\partial x_2}{\partial t}\right] = \frac{A - n_1(1-t)\{(4t\left[\frac{\partial x_1}{\partial t}\right] - 1)[p\left[\frac{\partial z}{\partial t}\right] - (1-z)\left[\frac{\partial p}{\partial t}\right]] + 4p(1-z)\left[\frac{\partial x_1}{\partial t}\right]\}}{2n_2d_2(1-\alpha)(1-t)^{\alpha} - 4n_1(1-t)\{t[p\left[\frac{\partial z}{\partial t}\right] - (1-z)\left[\frac{\partial p}{\partial t}\right] + p(1-z)]\}}$$

where $A = -(1-\alpha)[n_2 + pn_1(1-z)]$. Using this the pure strategy Nash equilibrium tax rate is the tax that solves

$$t = \frac{n_1[p\left[\frac{\partial z}{\partial t}\right] - (1-z)\left[\frac{\partial p}{\partial t}\right]] - (1-\alpha)[n_1 + pn_1(1-z)] + 2n_2d_2(1-t)^{1-\alpha}\left[\frac{\partial x_2}{\partial t}\right]}{p\left[\frac{\partial z}{\partial t}\right] - (1-z)\left[\frac{\partial p}{\partial t}\right]}.$$

The story is the same as for risk neutral individuals. The equilibrium tax rate is similar to the optimal tax levied in a single jurisdictional world, however it is distorted by the equilibrium migration response of the rich. As before this determines whether there will be under- or over-taxation compared to the optimal at the equilibrium. However constant relative risk aversion introduces a function of the tax rate in front of the equilibrium migration response.

This is not the only difference. Introducing constant relative risk aversion alters all the optimal taxes in the same way, irrespective of the anti-crime measure deployed. However when

benefits are paid to reduce crime the corollary no longer holds true; the tax rate that maximises the utility of the rich is no longer a pure strategy Nash equilibrium tax rate. Even when the poor have the same risk aversion the corollary disappears. Thus changing the attitude to risk does not alter the basic underlying result of tax competition resulting in a non-optimal tax being levied. The cause of the distortion, although different in magnitude, remains the same.

2.4.5 Policy implications

The theory has shown that when two jurisdictions compete in taxes to provide a police force that benefits the owners of capital it is possible for the resulting equilibrium taxes to be different from the optimal taxes levied by a federal government. If the jurisdiction's government aims to maximise the expected income of its residents then the tax receipts used to fund a police force will be higher or lower than optimal depending on the equilibrium migration response of the rich to a change in the domestic tax rate when there is imperfect labour mobility. Whilst this could result in increased safety being offered, the jurisdictions would be too safe. The clear policy implication is that devolving tax raising powers to fund the police force to a local level can result in non-optimal taxes being levied. Thus it is possible that the police force will be too small or too large when funded locally. In order to avoid this, the federal government needs to consider this outcome before devolving the tax raising power.

An oddity occurs when benefit payments are used as the anti-crime measure. Whilst the other anti-crime measures result in a tax which includes the distortion, the optimal tax for paying benefits eliminates the distortion. Thus the optimal benefit, from the rich group's perspective, can be paid to the poor irrespective of which level of government funds the anti-crime measure. It is difficult to tell whether the poor benefit from tax competition. When a police force is used the poor, as a group, will be worse off if the equilibrium tax is higher than optimal whilst they will be better off if the equilibrium tax is lower than optimal. A higher tax at the equilibrium increases the probability of apprehension and causes the level of crime to decrease. Thus overall the group becomes worse off. Ironically the possibility of increased

benefits due to tax competition is ruled out. Thus the one opportunity which benefits all the poor excludes the possibility of increased benefits being paid.

One consequence of non-optimal taxes being levied is it changes the extent to which a police force is funded and therefore can change the optimal anti-crime measure. If one method is most effective in a single jurisdictional environment (gives the rich the highest level of utility) then it will not necessarily do likewise in a two jurisdiction world as the distortion introduced to the equilibrium tax could be greater than for another anti-crime method. Thus another anti-crime methodology which has a less distorted tax could result in a greater utility being obtained by the rich overall. Therefore it is possible for tax competition not only to affect the tax rate levied but also to influence the anti-crime measure deployed.

2.5 A linear model

The preceding analysis concerns the equilibrium tax rates however empirical methods for detecting tax competition rely on the best response functions. For the generic model above it is difficult to find the best response functions due to the non-linear interaction between x_1 and x_2. Therefore to show the properties the best response functions are likely to have the model is re-written in a linear form.

2.5.1 Basic model

Let y_1 represent the proportion of criminals in the domestic region and y_2 the proportion of rich people in the same region. As before each group has an attachment to home measure of d_i and each group's location preference is uniformly distributed along the unit interval. The probability that a rich person (an individual who has a dividend income equal to one) is not a victim of crime is given by $\gamma_0+\gamma_1 t+\gamma_2(x_2-x_1)$ in the domestic region and $\gamma_0+\gamma_1 t^*+\gamma_2(x_1-x_2)$ in the foreign. The probability can be split into two parts. The first part, $\gamma_0+\gamma_1 t$ is the direct effect of the tax in reducing crime so as the tax rate of the jurisdiction increases better

protection is offered. The second part, $\gamma_3(x_i - x_j)$, is the indirect effect of the spillover.[23] If there are different tax rates in each of the jurisdictions then there can be different proportions of rich and criminals in them. If a jurisdiction has a higher proportion of criminals than rich each remaining rich individual faces a higher probability of being a victim of crime. These are the same properties as the previous model but are now in a linear manner. In order for there to be a taxed levied if there is only a federal government we assume $\gamma_0 < \gamma_1$, $\gamma_0 + \gamma_1 < 1$. If there is only a federal government setting taxes then the objective function is $\max(\gamma_0 + \gamma_1 t)(1 - t)$ which yields an optimal tax of $t = \frac{\gamma_1 - \gamma_0}{2\gamma_1}$.

Assume there are no crowding effects on criminals so the probability a criminal is successful in the domestic jurisdiction is $1 - \gamma_0 - \gamma_1 t$. The corresponding probability for the foreign jurisdiction is $1 - \gamma_0 - \gamma_1 t^*$. Therefore if utility functions are the same as before the marginal individual in each group is given by[24]

$$y_1(t, t^*) = \frac{d_1 + (1 - \gamma_0 - \gamma_1 t)(1 - t) - (1 - \gamma_0 - \gamma_1 t^*)(1 - t^*)}{2d_1} \tag{2.29}$$

and

$$y_2(t, t^*) = \frac{d_2 + (\gamma_0 + \gamma_1 t)(1 - t) - (\gamma_0 + \gamma_1 t^*)(1 - t^*) - \gamma_2 y_1(2 - t - t^*)}{2d_2 - \gamma_2(2 - t - t^*)} \tag{2.30}$$

As before if $t = t^*$ then $y_1 = y_2 = \frac{1}{2}$. The objective function for the domestic jurisdiction is $\max[\gamma_0 + \gamma_1 t + \gamma_2(y_2 - y_1)](1 - t)$. Optimising and applying symmetry, where $t = t^*$, the pure strategy Nash equilibrium tax rate is given by

$$t = \frac{\gamma_1 - \gamma_0 + 2d_2\left[\frac{\partial y_2}{\partial t}\right]}{2\gamma_1} \tag{2.31}$$

where

$$\frac{\partial y_2}{\partial t} = \frac{\gamma_0 - \gamma_1 + 2\gamma_1 t + 2\gamma_2(1 - t)\left[\frac{\partial y_1}{\partial t}\right]}{2\gamma_2(1 - t) - 2d_2}. \tag{2.32}$$

The pure strategy Nash equilibrium has the same structure as the more generic model; the tax is the same as the optimal tax but with the additional factor of the equilibrium migration

[23] This is a linear approximation of $\frac{x_i}{x_j}$. Note this model assumes policing is a private good; the nature of policing as a good is discussed in the next chapter.

[24] To simplify the model no sanction is imposed if a criminal is caught. Therefore this represents the prevention role of the police.

response of the rich. As before if the migration response is positive then the equilibrium tax will be higher than the optimal tax whilst if the equilibrium response is negative at the equilibrium the tax will be lower than optimal. In order to solve for specific values $d_1 = d_2 = \delta$ is assumed for the remainder of this section.

If we substitute equations (2.29) and (2.30) into the objective function of the domestic jurisdiction, differentiate with respect to t and set equal to zero we obtain the best response function. Applying symmetry we can solve for the (pure strategy) Nash equilibrium tax rate of

$$t = \frac{\gamma_2 + 2\delta(\gamma_1 - \gamma_0)}{\gamma_2 + 4\delta\gamma_1}. \tag{2.33}$$

This tax rate is always higher than the optimal tax as long as $\gamma_2 > 0$; in the absence of spillovers the tax levied will be the same as if only a federal government taxed. In order for this to be an optimal tax the necessary second order condition is $\frac{-[6\delta\gamma_1\gamma_2+8\delta^2\gamma_1^2+\gamma_2^2(1-\gamma_0-\gamma_1)]}{\delta(\gamma_2-2\gamma_1\gamma_2+4\delta\gamma_1-2\gamma_0\gamma_2)} < 0$. As the numerator is always negative it is necessary to assume the denominator is positive, or $\delta(\gamma_2 - 2\gamma_1\gamma_2 + 4\delta\gamma_1 - 2\gamma_0\gamma_2) > 0$. As such this model does not allow for perfect mobility ($\delta = 0$).

The properties of the equilibrium tax are as follows: $\frac{\partial t}{\partial \gamma_0} = \frac{-2\delta}{\gamma_2+4\delta\gamma_1} < 0$, $\frac{\partial t}{\partial \gamma_1} = \frac{2\delta(4\delta\gamma_0-\gamma_2)}{(\gamma_2+4\delta\gamma_1)^2}$, $\frac{\partial t}{\partial \gamma_2} = \frac{2\delta(\gamma_0+\gamma_1)}{\gamma_2+4\delta\gamma_1} > 0$ and $\frac{\partial t}{\partial \delta} = \frac{-2\gamma_2(\gamma_0+\gamma_1)}{(\gamma_2+4\delta\gamma_1)^2} < 0$. Both the optimal tax and the equilibrium tax respond in the same direction to a change in γ_0; if the probability of not being a victim of crime, irrespective of the tax policy of the government, increases then the tax levied will be reduced. Furthermore the optimal tax decreases more than the equilibrium tax as $\frac{-1}{2\gamma_1} < \frac{-2\delta}{\gamma_2+4\delta\gamma_1}$. Whilst the optimal tax is increasing in the effectiveness of the police, γ_1, the direction for the equilibrium tax is ambiguous. If there is low labour mobility (a high δ) then the response is more likely to be positive though if the spillover coefficient is large (γ_2) then the response is likely to be negative. The response of the equilibrium tax is clearly increasing in the spillover effect; slight differences in the proportion of each group living in a jurisdiction have a greater effect on the probability of being a victim of crime causing the tax to increase. The equilibrium tax is decreasing in labour mobility. As labour mobility approaches zero the

tax rate approaches one. Any increase in δ lowers the migration responses to a change in taxes and therefore allows lower taxes to be levied as they will attract fewer criminals. This property, which runs counter to the general tax competition literature, is discussed more in the following chapter.

In order to test the model with econometrics the properties of the best response function need to be investigated. The best response function used to calculate the Nash equilibrium above was totally differentiated and then re-arranged to give $\frac{\partial t}{\partial t^*}$. After this symmetry was applied where both jurisdiction's tax rates equal the Nash equilibrium to give the best response for the domestic jurisdiction to a change in the foreign jurisdictions's tax rate at the Nash equilibrium of[25]

$$\frac{\partial t}{\partial t^*} = \frac{\gamma_2[4\delta\gamma_1 + \gamma_2(1 - 2\gamma_0 - 2\gamma_1)]}{2[6\delta\gamma_1\gamma_2 + 8\delta^2\gamma_1^2 + \gamma_2^2(1 - \gamma_0 - \gamma_1)]} > 0. \tag{2.35}$$

The explanation for the positive response of the domestic jurisdiction to a change in the foreign jurisdiction's tax rate at equilibrium is the denominator is always positive whilst the numerator has to be positive in order to satisfy the second order condition above. The maximum value that it can take is one half. This can be proved by firstly differentiating with respect to γ_0. As the expression is decreasing in γ_0 we can substitute $\gamma_0 = 0$ and differentiate the resulting expression with respect to γ_1. This too is decreasing in the variable so substituting $\gamma_1 = 0$ gives the value of $\frac{1}{2}$.[26] Therefore if the foreign jurisdiction were to raise its tax at the equilibrium the domestic jurisdiction would respond by rasining their tax as well, though the increase would be at a maximum a half of the other jurisdiction's rise.

[25] As the empirical section tests the excess police precept, then removing the optimal tax from the best response, totally differentiating and re-arranging gives

$$\frac{\partial t}{\partial t^*} = \frac{4\delta\gamma_1 + \gamma_2(1 - 2\gamma_0 - 2\gamma_1)}{2[4\delta\gamma_1(1 + \gamma_0 + \gamma_1) + \gamma_2(1 - \gamma_0 - \gamma_1)]} > 0. \tag{2.34}$$

Thus for the difference in tax from the optimal the direction remains the same.

[26] Let $\frac{dt}{dt^*}\Big|_{t=t^*} = A$ then $\frac{\partial A}{\partial \gamma_0} = \frac{-\gamma_2^2(\gamma_2+4\delta\gamma_1)^2}{2[6\delta\gamma_1\gamma_2+8\delta^2\gamma_1^2+\gamma_2^2(1-\gamma_0-\gamma_1)]^2} < 0$. After substituting $\gamma_0 = 0$ into A then $\frac{\partial A}{\partial \gamma_1}\Big|_{\gamma_0=0} = \frac{-\gamma_2[\gamma_2^3+2\delta\gamma_2^2+16\delta^2\gamma_1\gamma_2(1-\gamma_1+32\delta^3\gamma_1^2)]}{2[6\delta\gamma_1\gamma_2+8\delta^2\gamma_1^2+\gamma_2^2(1-\gamma_1)]} < 0.$

2.5.2 Risk aversion

If we drop the assumption of risk neutrality and replace it with all agents having constant relative risk aversion of c and assume the aim of the government is to maximise the expected utility of wealth then the objective function for the domestic government becomes max $\frac{1}{1-c}[\gamma_0 + \gamma_1 t + \gamma_2(y_2 - y_1)](1-t)^{1-c}$ where y_1 and y_2 have altered to take account of the new functional form. If we further assume that $c = \frac{1}{2}$ then the (pure strategy) Nash equilibrium tax rate is given by

$$t = \frac{-\gamma_2^2 + 12\delta^2\gamma_1^2 - 6\delta^2\gamma_0\gamma_1 + \gamma_2\sqrt{\gamma_2^2 + 12\delta^2\gamma_1^2 + 12\delta^2\gamma_0\gamma_1}}{18\delta^2\gamma_1^2} \tag{2.36}$$

Whilst it is not shown here the best response function can be totally differentiated as before to show the best response of the domestic jurisdiction to a change in the foreign jurisdiction's tax at the equilibrium; the $\frac{\partial t}{\partial t^*} > 0$ property remains. If we make the same substitutions into it, namely that $\gamma_0 = \gamma_1 = 0$, then the value obtained is 3. Therefore if all agents have the same constant relative risk aversion then the response of the domestic jurisdiction to any tax changes by the foreign jurisdiction can be larger than would be obtained under the assumption of risk neutrality.

2.5.3 Horizontal and vertical tax competition

Assume now the federal government can levy a tax on all capital at rate s. This funding augments the tax raised locally so the probability a rich individual is not a victim of crime becomes $\gamma_0 + \gamma_1(s+t) + \gamma_2(y_2 - y_1)$ and $\gamma_0 + \gamma_1(s+t^*) + \gamma_2(y_1 - y_2)$ in the domestic and foreign jurisdictions respectively. In the timing of the game the federal government sets its tax first and then the local jurisdictions simultaneously set their taxes. Solving the game backwards gives the best response of the jurisdictions to the federal tax as

$$t = t^* = \frac{\gamma_2 + 2\delta(\gamma_1 - \gamma_0)}{\gamma_2 + 4\delta\gamma_1} - s. \tag{2.37}$$

Note that the effective tax charged $(s+t)$ is the same as when there is only horizontal tax competition. When this is substituted into the objective function of the federal government

(to maximise the income of the rich weighted by jurisdiction size so $W = y_2(1-s-t)[\gamma_0 + \gamma_1(s+t) + \gamma_2(x_2-x_1)] + (1-y_2)(1-s-t^*)[\gamma_0+\gamma_1(s+t^*)+\gamma_2(x_1-x_2)]$) it yields

$$W = \frac{2\delta(\gamma_2+2\delta\gamma_1)(\gamma_0+\gamma_1)^2}{(\gamma_2+4\delta\gamma_1)^2} \tag{2.38}$$

which is independent of the tax that it can levy, s. Recall $x_1 = x_2 = \frac{1}{2}$ when the federal government sets a tax as it does not alter the location decision of its citizens. Therefore at the equilibrium the same effective tax being levied as if there were no federal tax; the local tax is merely the difference between the competition tax rate and the federal tax rate.

Assume the government sets the tax rate at s then the best response of the domestic jurisdiction to a change in the foreign jurisdiction's tax rate at the equilibrium, keeping federal taxes fixed, is given by

$$\frac{\partial t}{\partial t^*} = \frac{\gamma_2\left[4\delta\gamma_1+\gamma_2\left(1-2\gamma_0-2\gamma_1\right)\right]}{2\left[6\delta\gamma_1\gamma_2+8\delta^2\gamma_1^2+\gamma_2^2\left(1-\gamma_0-\gamma_1\right)\right]} > 0 \tag{2.39}$$

The equation above is the same as in the absence of the federal government and therefore has the same properties. It is interesting to note that s appears nowhere. This is due to the jurisdictions having a aggregate equilibrium tax rate independent of the federal tax set. The response of the domestic tax rate to a change in the federal tax, keeping the foreign jurisdiction's tax fixed, is given by

$$\frac{\partial t}{\partial s} = \frac{-(\gamma_2+4\delta\gamma_1)^2}{2[6\delta\gamma_1\gamma_2+8\delta^2\gamma_1^2+\gamma_2^2(1-\gamma_0-\gamma_1)]} < 0 \tag{2.40}$$

The response is always negative with the greatest response being -1. Therefore if the federal government were to alter only the domestic jurisdiction's tax rate then it cause the domestic government to lower their tax rate though not enough to offset the government. When the response of the foreign jurisdiction is taken into account then it can be seen from equation (2.37) that it is perfectly negatively correlated (ie takes a value of -1). The jurisdictions have an ideal amount that rich individuals should be taxed so any increase in central taxes will be exactly offset by a decrease in local taxes.

The timing of the game reflects the system in England and Wales however it also ensures there is a Nash equilibrium in pure strategies. If all three governments were to set their taxes

simultaneously then the best response functions for the local jurisdictions require $s+t=\frac{\gamma_2+2\delta(\gamma_1-\gamma_0)}{\gamma_2+4\delta\gamma_1}$ whilst the federal government seeks to solve $s+t=\frac{\gamma_1-\gamma_0}{2\gamma_1}$. There are no pure strategy tax rates that ensure both these conditions hold meaning an equilibrium in mixed taxes exists.

2.5.4 Some simple dynamics

Assume now there is no federal government tax but the game is played for a second period. In the second period the dividend has increased by factor θ to $1+\theta$, the effectiveness of taxes by factor η to $(1+\eta)^{-1}\gamma_1$ and the attachment to home by ω to $(1+\omega)\delta$. Proceeding as before (assuming risk neutrality) gives a (pure strategy) Nash equilibrium tax of

$$\hat{t}=\frac{\gamma_2(1+\theta)(1+\eta)+2\delta(1+\omega)[\gamma_1(1+\theta)-\gamma_0(1+\eta)]}{\gamma_2(1+\eta)+4\delta\gamma_1(1+\omega)}. \tag{2.41}$$

which equates to a tax rise of

$$\frac{\hat{t}-t}{t}=\frac{\theta(\gamma_2+4\delta\gamma_1)[\gamma_2(1+\eta)+2\delta\gamma_1(1+\omega)]-2\delta\{4\delta\gamma_0\gamma_1\eta(1+\omega)+\gamma_2[\gamma_1(\omega-\eta)+\gamma_0\omega(1+\eta)]\}}{[\gamma_2(1+\eta)+4\delta\gamma_1(1+\omega)][\gamma_2+2\delta(\gamma_1-\gamma_0)]} \tag{2.42}$$

As would be expected if $\theta=\eta=\omega$ then the rise in tax is equal to θ meaning the tax rate remains unaltered. If θ is subtracted from equation (2.42) then the direction shows whether the Nash equilibrium tax has increased by more or less than the growth in income.

$$\frac{\hat{t}-t}{t}-\theta=\frac{2\delta\{4\delta\gamma_0\gamma_1(1+\omega)(\theta-\eta)+\gamma_2[\gamma_1(1+\theta)(\eta-\omega)+\gamma_0(1+\eta)(\theta-\omega)]\}}{[\gamma_2(1+\eta)+4\delta\gamma_1(1+\omega)][\gamma_2+2\delta(\gamma_1-\gamma_0)]} \tag{2.43}$$

If $\hat{t}t^{-1}-1-\theta>0$ then the tax rise between the two periods is greater than the rise in income resulting in an increased tax rate. There are two cases of interest. Firstly if income increases by the same amount as police costs ($\theta=\eta$) then the tax rate increases if $\theta>\omega$ otherwise it decreases. This is equivalent to the attachment to home measure taking on a different weight in the utility function and the tax rate changing accordingly. Secondly if income increases by the same amount as the attachment to home ($\theta=\omega$) then the tax will rise faster than income if either $\theta>\omega$ and $\gamma_2-4\delta\gamma_0>0$ or $\theta<\omega$ and $\gamma_2-4\delta\gamma_0<0$. As the direction of the equilibrium tax to a change in γ_1 is given by the direction of $4\delta\gamma_0-\gamma_2$ taxes will rise faster

than income if police costs rise by more than income and the equilibrium tax is increasing in γ_1 or the exact opposite of both statements hold jointly. Thus it is possible for the equilibrium tax to increase faster than income.

The change in the domestic tax, according to its best response function, to a change in the foreign tax rate calculated at the equilibrium is

$$\frac{\partial t}{\partial t^*} = \frac{\gamma_2(1+\eta)\{4\delta\gamma_1(1+\omega) - \gamma_2[2\gamma_1(1+\theta) + (1+\eta)(2\gamma_0 - 1)]\}}{2\{6\delta\gamma_1\gamma_2(1+\eta)(1+\omega) + 8\delta^2\gamma_1^2(1+\omega)^2 - \gamma_2^2(1+\eta)[\gamma_1(1+\theta) - (1+\eta)(1-\gamma_0)]\}} > 0 \tag{2.44}$$

Again the response of the domestic jurisdiction to a change in the foreign jurisdiction's tax rate at the equilibrium is greater than zero.[27] Again the maximum response remains one half (it can be shown in the same way as before). Therefore although the change is different (unless $\theta = \eta = \omega$) the values which it lies between remains the same.

2.6 Empirical evidence in England and Wales

Section four suggests tax competition for the provision of an anti-crime measure leads to the possibility of the rich being over or under taxed when capital and criminals are mobile, depending on the rich's equilibrium migration response to a change in tax. Section five, which has a more specific functional form, suggests tax competition will lead to higher taxes than optimal. Therefore the question arises: is there any evidence of tax competition occurring within England and Wales? Accordingly what follows is not a test of the economic model of crime (which, as indicated in section 2.1, has already been rigorously tested), rather the determinants of the extent to which crime is prevented and fought.

We begin by looking at the structure of funding in England and Wales. Scotland and Northern Ireland have a different policing structure and therefore will not be analysed here. A crude look at the figures suggest that there is a wide distribution of tax values inspite of the parity the standard spending assessment creates. Then regressions will be run to investigate

[27] Differentiating the objective function for the domestic government twice with respect to t gives the necessary second order condition at the equilibrium tax rate as $\frac{-\{6\delta\gamma_1\gamma_2(1+\eta)(1+\omega)+8\delta^2\gamma_1^2(1+\omega)^2-\gamma_2^2(1+\eta)[\gamma_1(1+\theta)-(1+\eta)(1-\gamma_0)]\}}{\delta(1+\eta)(1+\omega)\{4\delta\gamma_1(1+\omega)-\gamma_2[2\gamma_1(1+\theta)+(1+\eta)(2\gamma_0-1)]\}} < 0.$

whether or not interdependence between the authorities and the actual precepts they levy is present.

2.6.1 Local taxation and police funding in the UK

In the UK there is only one form of local taxation on individuals. The council tax came into being in April 1993 to replace the community charge. The community charge was a tax payable according to the number of people living in a house bearing no relation to the value of the property. This was seen as iniquitous as it made taxation independent of the ability to pay. Thus the council tax was in part a return to the domesticated rates that were collected before April 1990. The key difference is the exact value of a house no longer determined the amount payable, rather each house was put into one of eight bands with each band having its own tax. The link between the number of people living in the accommodation was partly dropped – people living alone in a property are eligible for a discount. Therefore housing returned to being a proxy for wealth and the subsequent ability to pay.

A proportion of the council tax goes towards the funding of the local police force. This, however, is not the only source of funding available to them. Their main sources of funding are: specific grant, revenue support grant, national non-domesticated rates and the council tax. The specific grant is the grant payable by the Home Office whilst the revenue support grant is handled by the Office of the Deputy Prime Minister. National non-domesticated rates are set by the government, collected locally, handed over to central government who then return them based roughly on the proportion of the adult population living in each police authority. The standard spending assessment shows how this money is to be distributed amongst the recipients each year reflecting some formulaic notion of justice. As proportions the police grant is approximately equal to the sum of the revenue support grant and national non-domesticated rates.

The final source of funding is the council tax. The contribution this makes to police authorities' budgets has increased from 10% in the mid 1990s to around 15% at the moment.

Each year the government sets out the total standard spending for the country detailing in the standard spending assessment the amount each police authority will receive. This includes a notional amount for council tax. This assessment means that if each police authority sticks to the plan, then the council tax levied for each valuation band will be the same throughout the country.[28] As police authorities themselves are recipients, we can calculate the precept that the central government thinks ought to be levied by

$$\overline{P} = \frac{S - R - B - O}{TB}$$

where $\overline{P}$ is the precept that ought to be levied by a police authority, S the amount designated by the standard spending assessment, R the total revenue support grant returned, B the amount of business rates returned, O other transfers from central government and TB the tax base calculated in the number of band D houses. These have been calculated on the totals of 41 police authorities in England and Wales (the Metropolitan Police and City of London Police have been excluded for reasons explained later). The levels are given at the bottom of table 1. In 2003/04 the government changed from standard spending assessments to formula funding share. Although the components remained the same it is constructed slightly differently and this accounts for the jump in the notional precept (and in table 4 the corresponding decrease in the excess precept in 2003/04).

Police authorities are not limited to this funding, rather they can then formulate their own budgets with any difference to be met locally. Thus 42 police authorities in England and Wales set the police precept which is included in the council tax.[29] Table 1 shows the percentage each police authority charged above the standard tax of central government for the past six years. This time frame is important as 1998/99 was the last year of universal capping by central government. Universal caps were a system whereby central government outlined both the standard spending assessment with its recommended spending level and the cap

[28]The total standard spending also lists the amounts to be transferred to local authorities to enable them to carry out their other responsibilities. Therefore equality in the council tax bands will only be achieved if all of these budgets are stuck to by all of the authorities as well.

[29]The City of London police force is excluded from the analysis due to its low resident population but high daytime one; the nature of policing there is different and accordingly is funded differently.

Table 2.1: Band D police precepts in relation to the notional precept

	1998/1999	1999/2000	2000/2001	2001/2002	2002/2003	2003/2004
Up to 10%	14	11	6	6	2	11
10% to 20%	13	8	8	7	1	8
20% to 30%	7	9	6	7	7	8
30% to 40%	1	4	6	4	5	5
40% to 50%	5	3	4	3	4	6
50% to 60%	1	5	6	9	2	1
60% to 70%	1	2	5	4	12	1
70% to 80%			1	1	5	1
80% to 90%					3	1
90% to 100%						
Over 100%				1	1	
Notional precept	48.36	50.30	51.73	55.21	56.88	88.10

Data source: Finance and general statistics (CIPFA, London); Standard Spending Assessment (ODPM, London).

which was the maximum permitted spending by the police authority. Only the Metropolitan Police authority was exempt from having a cap. Although the cap when set was not legally enforceable (a precepting authority could set a spending amount above that, a cap would then be sought by central government and Parliament would then have to vote on whether or not to enforce the cap), Emmerson et al. (1998) report that it acted as a cap. This can be observed by 23 of the authorities setting spending at the level of the cap in 1998/99, 11 were less than 0.1% under the spending cap and the remaining 6 were up to 1.6% underneath it. Of those four were all the Welsh police authorities underspending by 1.4%, 1.5%, 1.5% and 1.6%.

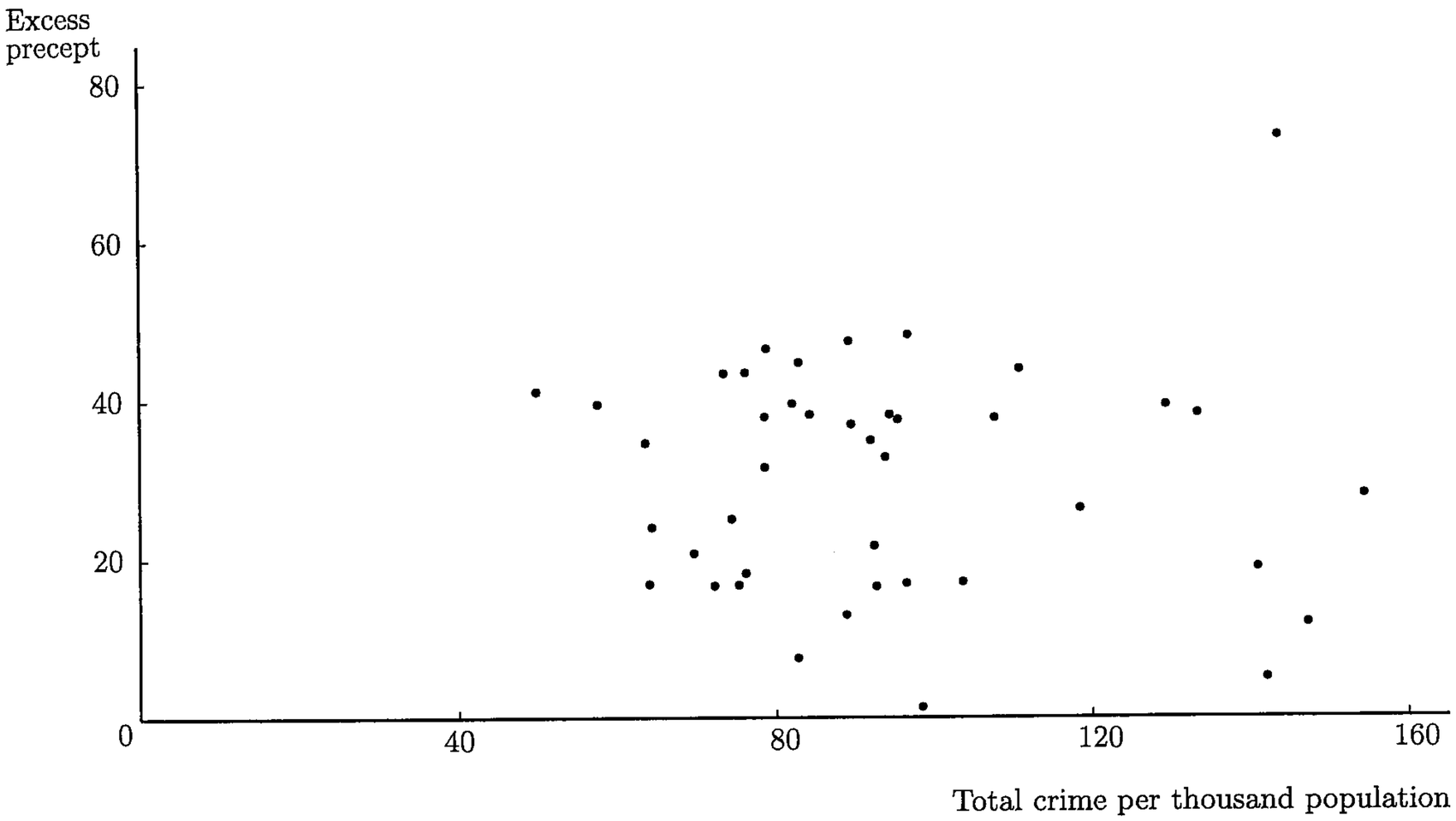
Changes by the government meant they retained the power to cap in subsequent years but no longer set an explicit capping limit with the standard spending assessment. Thus in the following five years the police authorities were able to levy an uncapped precept giving more scope for tax competition between them. For the year 2004/2005 the government considered capping the budgets of Cumbria, Northamptonshire and West Mercia and threatened caps in subsequent years if the rises were considered excessive. A look at the figures show that taxes levied by authorities have been rising faster than recommended according to central government. The most obvious explanation for differences in excess precepts is that they are responding to different levels of crime in the jurisdictions. Figure 2.1 gives a scatter graph

Table 2.2: Band D police precepts

	1998/1999	1999/2000	2000/2001	2001/2002	2002/2003	2003/2004
Mean	57.50	63.11	68.98	74.98	87.27	109.39
Standard deviation	8.46	9.49	10.81	13.31	14.47	20.08
Minimum	47.67	49.82	52.06	55.65	58.15	63.80
Maximum	78.93	82.51	90.95	118.85	130.59	159.13

Data source: Finance and general statistics (CIPFA, London).

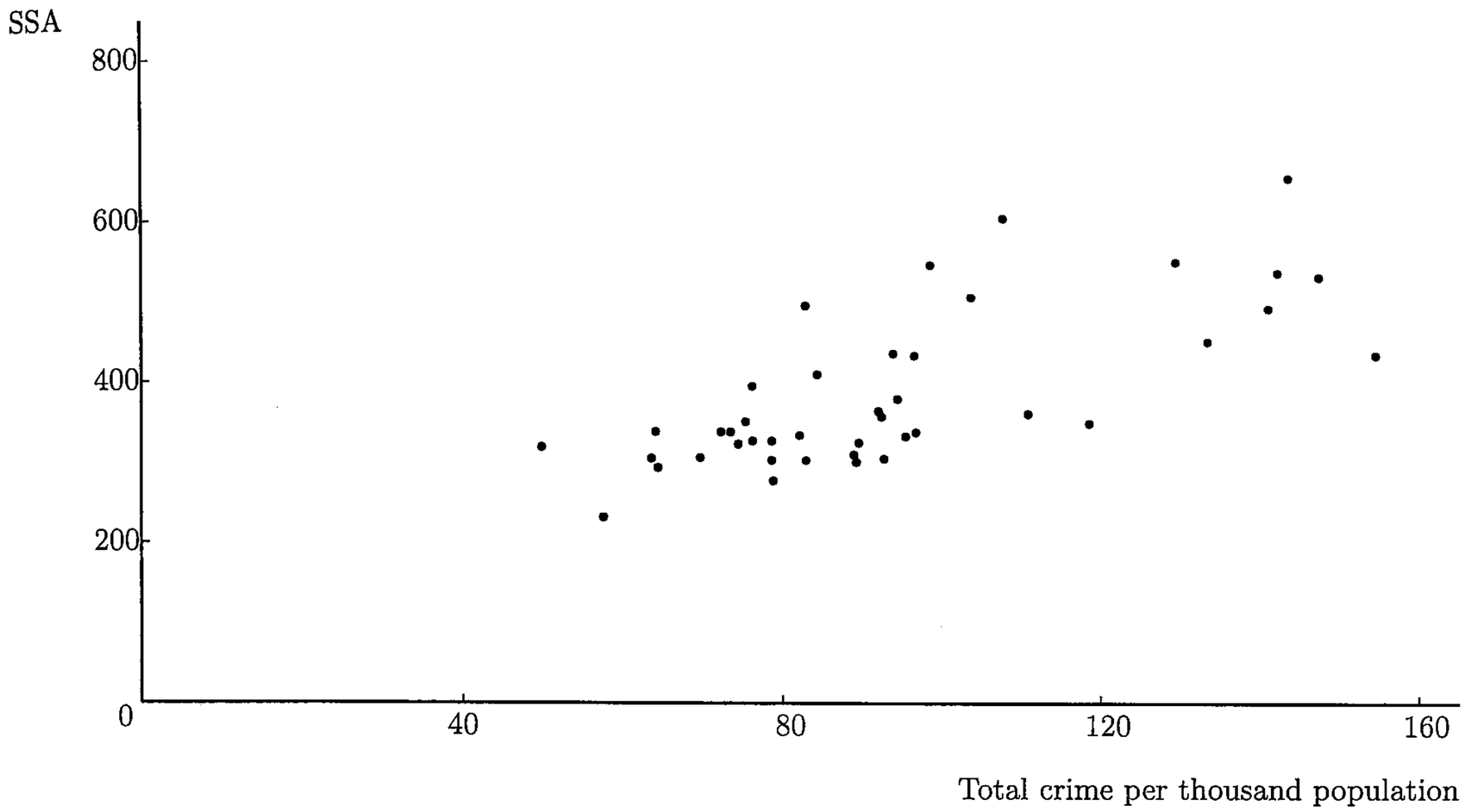
Figure 2.1: Band D excess precept against total crime 2002/03



plotting total crime per thousand population against the excess precept for 2002/03. There is a lack of correlation between the level of crime and the precept levied by the police authority; there is a product-moment correlation coefficient of -0.0201 and Spearman's coefficient of rank correlation of -0.0495. This lack of correlation can possibly be explained by the standard spending assessment.

Figure 2.2 gives a scatter graph plotting total crime per thousand population against the standard spending amount per band D equivalent. Here the product-moment correlation coefficient of 0.7072 and a Spearman's rank correlation coefficient of 0.7226. It is not surprising there is a positive correlation between total crime and the standard spending assessment. The

Figure 2.2: SSA per band D equivalent against total crime 2002/03



determinants of the standard spending assessment are similar to those that cause crime (for example the level of young male unemployment, the proportion of long-termed unemployed and proportion of striving population) and those associated with policing (the number of police stations, pensions costs, length of motorways). The standard spending assessment aims to ensure each police authority receives the necessary funding to provide a uniform service. Superficially the excess precept is uncorrelated with the level of crime in a jurisdiction as it is already accounted for in the standard spending assessment.

Unfortunately there are two problems associated with using precepts in empirical work: gearing and comparing. The problem of gearing connects council tax increases to the increase in local expenditure. As council tax receipts form a relatively small proportion of overall police funding, any increase above that specified by central government has to be met locally. For example, suppose a government decides to increase spending by $a\%$ whilst the local authority prefers to increase expenditure by $b\%$, where $a < b$. The proportion of the budget to be met by local taxes is c. To accommodate the local authorities wishes the council tax would have to rise by $\left(a + \frac{b-a}{c}\right)\%$, which is greater than b. Each additional unit increase in police

expenditure over and above that demanded by central government increases local taxes by $\frac{1}{c}\%$. Therefore a large increase in the council tax does not necessarily translate into such an increase in police expenditure. (APA 1999).

The second problem concerns comparing one jurisdiction's tax rate to another's. Of the eight bands, band D is used as the average. A band D house is defined as a house that would achieve a price of between £68,000 and £88,000 in England if sold on the open market by a willing vendor on 1st April 1991. The Local Finance Act of 1992 sets the ratio between the bands as being 6:7:8:9:11:13:15:18 (from band A to band H). Therefore a house in band H (a value of above £320,000 on 1st April 1991) pays twice the average council tax whilst a house in band A (worth less than £40,000) pays two-thirds the average. As a council needs to raise a set sum to satisfy its budget, the composition of the property values affects the average band D council tax. Consider two jurisdictions each containing one household. If each jurisdiction needs to raise £100 and the first jurisdiction house is in band A whilst the second is in band H then the average council tax charged will be £150 and £50 respectively. Thus if comparing levels, an area where the property is valued relatively lower would be expected to exhibit higher average council taxes without an apparent increase in the quantity of services provided.

2.6.2 Testable implications

The preceding subsection shows there is a wide variation in the excess precepts levied by police authorities. The theory in section four has few testable implications as its results are dependent on knowing the optimal tax to levy. If taxes are greater than optimal and labour mobility is imperfect then one explanation is tax competition with the rich population having a positive equilibrium migration response to a change in taxes. This means if the other jurisdiction were to increase its tax rate then it would attract some of the rich population. Unfortunately the optimal taxes to levy, with regard to policing, are unknown. If we assume they are those consistent with the standard spending assessment then it would suggest there is a desire for increased security in England and Wales as the majority of excess precepts levied

in the panel are positive. Table ?? shows the excess precepts levied. As was stated previously there is a break in 2003/04 when central funding changed from the standard spending assessment to the formula funding share with the majority of the excess precepts decreasing due to the large increase in the notional precept. Even then only 4 jurisdictions levied a tax below the notional tax (and one of these had a positive excess precept the following year). The only other negative excess precept is Northumbria in 1999/2000. However the standard spending assessment is associated with a consistent level of security and not necessarily the optimal level. As such this conclusion is dependent on the strong assumption of the standard spending assessment providing the optimal level of security.

The theory from section five however is testable. The theory assumes a more specific functional form but it shows that at the equilibrium taxes will respond positively to any increase in taxes by the other police authorities. Therefore it is possible to test the best response functions by regressing the excess precepts of all the other jurisdictions onto the excess precept and seeing if it possesses a positive coefficient.

2.6.3 The determinants of the police precept

In empirical investigations for tax competition there are two main methods that have been used. Spatial autoregressive models test the equilibrium itself to estimate the spatial lag. As the equation to be estimated is non-linear it needs to be estimated using maximum likelihood (for example Anselin 1988). The second approach tests the best response functions using instrumental variables. It is this approach that we adopt basing the methodology on Devereux, Lockwood and Redoano (2002).

The equation we wish to investigate can be written as

$$P_{it} = \overline{P}_t + \alpha_i + \sum_{j \neq i} \beta_{ij} P_{jt} + \gamma' X_{it} + \epsilon_{it}$$

where P_{it} represents the precept levied by jurisdiction i in time t ($i = 1, ..., 42$ and $t = 1, .., 5$), $\overline{P}$ the notional precept and X_{it} other variables that can affect the precept levied by a jurisdiction. As there are 42 police authorities it is not possible to calculate all $42 \times 41 = 1722$

β_{ij} so it is assumed that all police authorities respond symmetrically to their appropriately weighted competitors' average precept. This means the equation to be estimated can be written as

$$P_{it} = \overline{P}_t + \alpha_i + \beta \sum_{j \neq i} \omega_{ij} P_{jt} + \gamma' X_{it} + \epsilon_{it}$$

where ω_{ij} is a row stochastic spatial weight matrix. As it is possible for crime and the excess precept to be simultaneously determined we need to us instrumental variables for the crime measure. Therefore we use a three step estimation process. Firstly we regress crime using the square of standard spending assessment per band D equivalent, expected punishments as additional instruments[30] and the number of dwellings on crime. This allows for any possible simultaneity there might be between the excess precept and crime. The fitted values are calculated and then used as the crime measure in X_{it}. The second step is to regress $P_{it} - \overline{P}_t$ on X_{it}, estimating the values of P_{it} and use these values to calculate the average weighted neighbours' precept. The final step is to regress $P - \overline{P}_t$ on these and X_{it}.

So far we have only mentioned the properties of ω_{ij} without mentioning how it is determined. There is no endogenous method of determining who an appropriate neighbour of a jurisdiction is. We consider two different methods of determining an appropriate neighbour – contiguity and social and economic characteristics. Both methods have arguments supporting their use. Contiguity fits the theoretic model with people locating in an area for employment reasons and then in choosing where to live will compare the jurisdictions for the security they offer. Thus each police authority will compete in order to attract them. As such each jurisdiction is competing only with its direct neighbours. Geographically based weight matricies are the most common form of weight matrix in spatial econometrics as they can measure direct spillover effects (going back to Anselin (1988)). Therefore we let $\omega(G)$ be a matrix of geographic neighbours where the ij^{th} entry is 0 if i does not neighbour j and $\frac{1}{k}$ if i neighbours j, where k represents the number of non zero entries on row i.

Another argument of the model is that crime follows from social and economic circum-

[30]These have been calculated as the proportion found guilty multiplied by the average custodial sentence for both juveniles and adults at magistrate and Crown courts.

stances and therefore police forces can only be compared to other police forces with similar social and economic characteristics. In terms of the location decision of rich individuals, they will settle in the jurisdiction near their place of employment where the police force is doing well in comparison to others. Therefore a neighbour can be defined as any jurisdictions that have similar social and economic circumstances irrespective of geography; this definition goes back to Case et al. (1993). In 2003 for the first time the Home Office issued police performance monitors which aim to show the performance of each police force compared to police forces which have been cited by Her Majesty's Police Inspectorate (Home Office (2003)) as having similar social and economic characteristics. These "similar forces" have subsequently been changed for the figures reported in 2004. Therefore let $\omega(r)$ be a matrix of similar policing neighbours where $r = 2002$ or $r = 2003$ depending on the police standards report and where the ij^{th} entry is $\frac{1}{l}$ if the police consider i to be similar to j and 0 otherwise, with l representing the number of non zero entries on row i. From the police's viewpoint neighbours are not necessarily symmetric and therefore $\omega(r)$ itself is not symmetric.

Additionally CIPFA have a Nearest Neighbours Selection Model on their website[31] which allows neighbours to be selected using various social and economic criteria. We assume the Welsh police authorities only compete with other Welsh police authorities, the English metropolitan police authorities compete only with other English metropolitan police authorities and English non-metropolitan police authorities compete with other English non-metropolitan police authorities. Therefore the matrix $\omega(m)$ represents the weight matrix when the jurisdiction competes only with its m closest social neighbours, with the ij^{th} entry $\frac{1}{m}$ if j is one of i's m closest social neighbour and 0 otherwise. All spatial weights are assumed to be fixed over time.

The regressors used are the number of crimes committed per 1,000 population, the clear-up rate, number of population per policeman, population, area, proportion of band A houses, proportion of band G and band H houses, the average weighted house value, the standard

[31] http://www.ipf.co.uk/sis/nearestneighbours/police/default.asp

spending assessment per band D equivalent household and the lagged excess precept. We have used levels. Crime and its clear up rate have been lagged by one year to reflect the information available when the precept is to be set. The model suggests that the standard spending assessment should have a negative effect on the excess precept as an increase in central government funding lowers the tax the jurisdictions levy. Given the relationship between crime and the standard spending assessment it is unknown whether the standard spending assessment fully allows for the level of crime or if jurisdictions still need to raise excess precepts. The proportion of houses is included to be a proxy for wealth in the jurisdiction with band A representing low wealth and bands G and H higher wealth. The average weighted house value is the proportion of the band D police precept the average house pays. This allows for comparisons to be made between the jurisdictions even though they have different value housing stocks. It would be expected that this had a negative coefficient as jurisdictions with higher valued housing stocks can levy a lower tax and still raise the same sum.

2.6.4 Data

The source of data concerning local government statistics is CIPFA. The data on local precepts and the composition of houses in each authority (proportions of band A and bands G and H along with the average weighted house) have been constructed from Council Tax Demands and Precepts whilst details on the population size, area and population per policeman for the forthcoming year have been taken from Police Estimates. Data on crime statistics is taken from the Home Office publication Criminal Statistics.

Criminal Statistics are the official measure of crime in society; these are the crimes that are reported and recorded. MacDonald (2002) criticises the official crime statistics due to discrepencies between them and the British Crime Survey (a victimisation survey). Even if the under-reporting of crime was systematic, there is no victimisation study in England and Wales that breaks down data to local authority level, only regional. Further there is no reason to suppose that there are significant geographic variations. The Probit estimates of factors

Table 2.3: Descriptive statistics

	Mean	Standard deviation	Minimum	Maximum
Number of crimes per 1000 population	93.1	25.2	47.6	159
Percentage of crimes solved	29.1	8.8	14	68.6
Population per police man	463.4	71.4	250	581
Population	1253336	1083360	480700	7368500
Area	358985.7	242528.7	59887	1095851
Average weighted house	0.814	0.090	0.672	1.093
Proportion of band A properties	0.274	0.173	0.016	0.639
Proportion of band G and H properties	0.035	0.029	0.007	0.170
Standard spending assessment	388.7	102.7	174.3	720.7
Lagged excess	17.87	13.54	-0.69	73.71
Police precept over $\overline{P}$	20.30	15.15	-24.30	73.71

that influence people to report burglary crimes calculated by MacDonald are insignificant for most of England and Wales.[32]

The measures used to reflect the measure of crime in the jurisdictions are total number of crimes per 1,000 population and total number of property crimes per 1,000 population. Property crime here is defined as the aggregate of the following offences: robbery, burglary, theft and handling stolen goods, fraud and forgery, and criminal damage. Although robbery in official statistics is recorded as a violent crime, it is also a crime to gain property and is included to reflect this. Also available are the corresponding clear-up rates.

2.6.5 Results

As there is no test for choosing an appropriate weighting matrix the same model was estimated using all the weight matrixes. Table 5 gives the results when total crime per 1000 population was used as the crime measure whilst table 6 gives the results when property crime per 1000 population was used. The first column gives the results when horizontal tax competition is excluded whilst the remaining columns detail when horizontal tax competition is taken into account. Starting with table 5, of all the control variables used population was always statistically significant suggesting larger police forces have higher excess precepts. The area

[32]Only two regions compared to London proved to be significant: North West England (at the 5% level) and East England (at the 10% level). The other seven regions were statistically insignificant.

covered, by contrast, was statistically insignificant (apart from when the excess precepts of the other jurisdictions were not taken into account). Controls for income show jurisdictions with a larger proportion of low value housing stock had lower excess precepts whilst those with a larger proportion of higher value housing stock had higher excess precepts, however the effect of the rich was mainly statistically insignificant. This implies relatively poorer jurisdictions have lower excess precepts. As expected the control for housing stock has a negative coefficient meaning jurisdictions with a lower value average house have a higher excess precept due to the manner in which the band D equivalent is constructed. Although the coefficient for population per policemen is always negative it is barely significant when horizontal tax competition is included suggesting police numbers relative to the population are also accounted for by the transfers from central government. Finally the percentage of crimes solved came back with a negative coefficient which states jurisdictions with a better detection rate have lower excess precepts. One possible explanation could be jurisdictions respond to a low detection rate by increasing the precept to be able to devote more financial resources to detection.

Whichever weighting was used the level of crime in the jurisdiction was statistically insignificant in determining the excess precept. This would suggest central government transfers adequately control for the level of crime in a jurisdiction and jurisdictions do not have to levy extra taxes to account for the security situation. Given the correlation between crime and the standard spending assessment this result would be expected. As the model predicted the coefficient for the standard spending assessment per band D equivalent is negative. For each extra pound central government allocates to a police authority it reduces the excess precept by twenty to thirty pence. The lagged excess precept was also always statistically significant suggesting a level of persistence.

Of the five neighbour weighting matricies used three were significant at the five percent level whilst the remaining two were significant at the one percent level. All of them were positive as the model suggested though their values ranged from 38 to 75 pence in the pound which in terms of the model suggests there is some risk aversion. The matricies which produced

the highest significance were $\omega(2002)$ and $\omega(6)$. The police's own initial 2002 similar forces suggest a response of 75 pence in the pound however when the similar forces were altered for the following year this decreased to 38 pence in the pound and less statistical significance. Although the weighting matricies were kept fixed for the fives years of the panel it will be interesting to see whether the change in similar forces for inspection purposes will lead to this weighting becoming the most significance. Table 6 presents the results when property crime is used as the measure of crime. As property crime is approximately 75% of total crime (Home Office, 2006) the results are similar to those for total crime, namely the crime level does not explain the excess precept, the SSA has a negative effect and there is statistical evidence of tax competition between the jurisdictions with similar magnitudes. There is one difference, though, which is the percentage of crime solved is now insignificant in half the specifications.

2.7 Conclusion

The model presented looks at how the tax rates levied by local government to fund their local police services are influenced by the movement of the rich and poor between the jurisdictions. The tax receipts are used to fund anti-crime measures aimed to increase the expected income of the rich by trying to lower the level of crime (transfers and incarceration) or the expected loss from crime (fines). Both the owners of capital and the potential criminals are mobile between the jurisdictions; their movement is dependent not only on the tax rate levied but also the movement of the other group. When the jurisdictions compete in taxes to maximise the expected income of the rich the resulting symmetric pure strategy Nash equilibrium is distorted by the equilibrium migration response of the rich to a change in the equilibrium tax. If the migration response is positive at the equilibrium then the equilibrium tax will be higher than optimal whilst if it is negative then the equilibrium tax will be lower than optimal. Consequently too many or too few resources can be devoted to anti-crime measures if their funding is devolved to local jurisdictions with too little or too much crime compared to the optimum. However it is possible for this distortion to also alter the choice of anti-crime

measure.

The model was influenced by the precepting powers given to police authorities in England and Wales. Each police force is able to determine its own funding through issuing a police precept. These police precepts have been deviating over time from the notional precept central government views as being appropriate. Therefore the best response functions of a linear version of the model were tested using five years of data from 41 police authorities in England and Wales. The model states the tax will be increasing in the tax rates set by the other jurisdictions whilst it is decreasing in funding from the central government. The predictions of the model are borne out in the empirics. The results suggest the presence of police authorities engaging in tax competition cannot be ruled out. Further an increase in government funding decreases the excess precept charged by police forces. Interestingly crime is statistically insignificant in determining the excess precept – the implication of this is the standard spending assessment seems to give sufficient funding to police forces to deal with the crime they face.

The policy implication of this chapter is careful consideration should be given to which level of government has the ability to raise taxes for policing. If it is devolved to the local government level then the resulting taxes can be distorted away from the optimum. The next chapter details one circumstance when the tax raising power can be devolved without the distortion occurring, however this could entail problems at the federal level.

Table 2.4: Excess police precepts by jurisdiction

	1999/2000	2000/2001	2001/2002	2002/2003	2003/2004	2004/2005
Avon and Somerset	10.32	15.86	17.45	26.52	23.54	32.30
Bedfordshire	11.06	15.25	15.05	21.81	5.34	14.38
Cambridgeshire	1.81	10.73	12.83	37.71	25.21	36.43
Cheshire	5.98	9.33	9.45	16.66	0.00	4.92
Cleveland	12.25	13.85	14.30	39.25	32.12	44.05
Cumbria	27.97	32.50	35.39	43.60	42.61	57.49
Derbyshire	15.55	19.39	20.17	35.08	23.67	30.09
Devon and Cornwall	3.22	7.14	6.60	16.92	15.17	20.60
Dorset	26.83	32.69	37.04	46.62	35.29	42.57
Durham	0.10	0.92	1.22	7.56	-8.54	-1.26
Dyfed Powys	22.69	33.68	35.69	41.22	36.01	49.86
Essex	14.77	16.22	15.80	20.79	4.87	6.48
Gloucestershire	18.60	26.25	26.84	37.13	54.49	63.92
Greater Manchester	9.92	10.99	9.45	11.98	3.55	5.73
Gwent	9.44	23.24	28.82	38.29	31.01	46.34
Hampshire	3.61	3.35	3.83	18.27	9.19	15.57
Hertfordshire	13.24	16.26	17.18	24.13	10.18	19.74
Humberside	4.51	8.57	30.56	38.52	24.94	37.17
Kent	2.18	4.00	5.05	16.76	6.85	12.87
Lancashire	7.39	10.87	12.68	16.98	-0.53	7.91
Leicestershire	13.49	16.07	20.31	38.33	16.67	27.32
Lincolnshire	31.69	34.76	35.15	37.98	16.30	19.44
Merseyside	27.14	29.58	30.16	37.88	13.44	17.38
Metropolitan	32.21	39.22	63.64	73.71	71.03	91.29
Norfolk	14.05	20.36	28.40	43.47	33.85	45.90
Northamptonshire	25.78	27.92	27.79	48.37	41.99	56.64
Northumbria	-0.48	0.33	0.44	1.27	-24.30	-25.86
North Yorkshire	1.90	5.31	7.38	31.71	67.90	78.71
North Wales	16.03	26.76	27.51	39.65	38.84	58.78
Nottinghamshire	11.25	13.44	14.96	28.29	21.20	27.33
South Yorkshire	6.42	7.53	7.58	17.21	6.20	10.00
South Wales	15.06	28.69	30.36	32.97	15.41	22.92
Staffordshire	28.56	31.70	39.16	44.05	38.40	45.65
Suffolk	5.86	9.38	11.93	25.20	21.25	26.91
Surrey	24.94	27.68	27.87	39.56	46.99	54.27
Sussex	2.89	3.80	3.92	12.96	9.64	12.33
Thames Valley	6.23	8.61	9.28	16.61	18.14	27.72
Warwickshire	20.88	25.84	29.96	44.90	29.20	33.76
West Mercia	8.70	22.33	23.29	47.62	31.70	44.90
West Midlands	0.89	3.04	2.00	5.00	-16.94	-12.71
West Yorkshire	4.46	7.00	5.61	19.04	0.71	9.27
Wiltshire	18.68	24.11	28.05	34.66	21.58	27.84

Table 2.5: Determinants of the precept above its notional value using total crime

	IV	IV $\omega(G)$	IV $\omega(2002)$	IV $\omega(2003)$	IV $\omega(5)$	IV $\omega(6)$
Total number of crimes per 1000 population	0.2169 (1.42)	0.0925 (0.61)	-0.0335 (0.19)	0.0761 (0.47)	0.0648 (0.39)	-0.0025 (0.02)
Percentage of total crime solved	-0.7168*** (4.04)	-0.5061*** (2.67)	-0.3229* (1.78)	-0.5113*** (2.79)	-0.4438** (2.33)	-0.3089* (1.71)
Population per policeman	-0.0968** (2.28)	-0.0567** (2.04)	-0.0256 (0.88)	-0.0496 (1.57)	-0.0306 (1.01)	-0.0204 (0.70)
Population	0.1383*** (3.62)	0.1133*** (3.25)	0.1565*** (4.65)	0.1386*** (4.40)	0.1508*** (4.52)	0.1669*** (4.99)
Area	0.1594* (1.81)	0.0616 (0.69)	-0.0122 (0.14)	0.0504 (0.58)	-0.0518 (0.66)	0.0 471 (0.61)
Average weighted house	-1.0017*** (2.79)	-0.9903*** (2.68)	-0.9128** (2.55)	-0.9905*** (2.67)	-1.0157*** (2.79)	-1.0097*** (2.74)
Proportion of A band properties	-0.9942*** (3.21)	-0.7974*** (2.78)	-0.6234* (1.85)	-0.8918** (2.53)	-0.8910*** (2.66)	-0.7422** (2.25)
Proportion of G and H band properties	3.5321** (2.29)	1.9478 (1.21)	2.1416 (1.48)	2.5130 (1.46)	2.0788 (1.24)	1.7581 (1.10)
Standard spending assessment	-0.3825*** (8.87)	-0.3319*** (7.81)	-0.2389*** (3.83)	-0.3054*** (4.82)	-0.2612*** (4.02)	-0.2430*** (4.38)
Lagged excess precept	0.6144*** (4.36)	0.5756*** (4.10)	0.4374*** (3.14)	0.5507*** (3.85)	0.4549*** (2.92)	0.4341*** (3.03)
Weighted neighbour's tax		0.4846** (2.45)	0.7474*** (4.10)	0.3833** (2.14)	0.4746** (2.54)	0.6813*** (3.61)
R^2	0.8546	0.8641	0.8737	0.8616	0.8644	0.8714
Sargan test statistic	0.4662	0.2119	5.0956	2.0429	1.9246	1.9383
LM test statistic	0.9605	0.081	0.091	0.1798	0.5041	0.8350

Police authority effects have been included in all regressions. Figures in brackets show the robust t-statistics. *** denotes significance at the 1% level, ** at the 5% level and * at the 10% level. Coefficients for proportion of properties and area have been multiplied by 10^3 whilst those for average weighted house have been multiplied by 10^{-3}. Instruments used for crime are SSA, SSA^2, number of dwellings, expected punishment if caught for both juveniles and adults in magistrates and Crown courts. The Sargan test is distributed $\chi^2(5)$ when weighted neighbour's tax is included, $\chi^2(6)$ when not. The LM test statistic is for autocorrelation distributed $\chi^2(1)$.

Table 2.6: Determinants of the precept above its notional value using property crime

	IV	IV $\omega(G)$	IV $\omega(2002)$	IV $\omega(2003)$	IV $\omega(5)$	IV $\omega(6)$
Number of property crimes per 1000 population	0.2204 (1.29)	0.1115 (0.66)	-0.0235 (0.12)	0.0856 (0.48)	0.0811 (0.45)	0.0199 (0.11)
Percentage of property crimes solved	-0.7135*** (3.80)	-0.4424** (2.18)	-0.2622 (1.31)	-0.4607** (2.23)	-0.3664 (1.64)	-0.1868 (0.88)
Population per policeman	-0.0700** (2.24)	-0.0573** (2.00)	-0.0282 (0.95)	-0.0507 (1.59)	-0.0314 (0.98)	-0.0213 (0.70)
Population	0.1440*** (3.72)	0.1192*** (3.31)	0.1595*** (4.73)	0.1440*** (4.53)	0.1565*** (4.60)	0.1731*** (5.08)
Area	0.1235 (1.34)	0.0419 (0.44)	-0.0276 (0.31)	0.0269 (0.31)	-0.0370 (0.45)	0.0415 (0.50)
Average weighted house	-0.9202** (2.52)	-0.9437** (2.56)	-0.8737** (2.42)	-0.9289** (2.47)	-0.9729*** (2.66)	-0.9889*** (2.70)
Proportion of A band properties	-0.9551*** (3.06)	-0.7911*** (2.74)	-0.6322* (1.82)	-0.8634** (2.43)	-0.8857*** (2.61)	-0.7512** (2.23)
Proportion of G and H band properties	3.6331** (2.29)	2.0507 (1.30)	2.2530 (1.61)	2.5757 (1.54)	2.1689 (1.31)	1.8216 (1.16)
Standard spending assessment	-0.3781*** (8.58)	-0.3322*** (7.76)	-0.2413*** (3.86)	-0.3033*** (4.72)	-0.2596*** (3.84)	-0.2417*** (4.28)
Lagged excess precept	0.5909*** (4.17)	0.5607*** (3.97)	0.4256*** (3.03)	0.5310*** (3.68)	0.4376*** (2.75)	0.4177*** (2.88)
Weighted neighbour's tax		0.4842** (2.37)	0.7588*** (4.02)	0.3998** (2.12)	0.4854** (2.41)	0.7094*** (3.54)
R^2	0.8529	0.8619	0.8727	0.8603	0.8626	0.8700
Sargan test statistic	0.4179	0.1287	4.9049	1.9542	1.6013	1.6230
LM test statistic	0.7974	0.4646	0.5061	0.3188	0.6414	0.9363

Police authority effects have been included in all regressions. Figures in brackets show the robust t-statistics. *** denotes significance at the 1% level, ** at the 5% level and * at the 10% level. Coefficients for proportion of properties and area have been multiplied by 10^3 whilst those for average weighted house have been multiplied by 10^{-3}. Instruments used for crime are SSA, SSA^2, number of dwellings, expected punishment if caught for both juveniles and adults in magistrates and Crown courts. The Sargan test is distributed $\chi^2(5)$ when weighted neighbour's tax is included, $\chi^2(6)$ when not. The LM test statistic is for autocorrelation distributed $\chi^2(1)$.

Chapter 3

A general model of tax competition and crime

The previous chapter considered the effect tax competition has on tax rates and crime when the capital itself is subject to the possibility of theft. This chapter relaxes the assumption that the post tax income of the rich is the object of a criminal's desire to allow for other crimes committed against the rich. Irrespective of the type of crime committed it is assumed a criminal will gain a fixed amount of utility from committing a crime but loose a fixed amount if they are subsequently apprehended and a sanction imposed. Similarly the owner of the capital suffers a fixed reduction in their utility if they are subject to crime. Therefore in this chapter it is not the capital that is subject to crime, rather the owners of the capital.

The chapter begins by introducing a generalised model of crime, though it is introduced into the same Hindriks type model as the previous chapter. The presence of a police force has two separate effects. The first is the direct effect it has on detection. This, in turn, influences the second effect, the participation in crime decision. As before both groups are mobile across the jurisdictions. Each individual's location decision is dependent on the movement of others, which are influenced by the taxes levied by the local jurisdictions to fund the police service. After introducing the base model, which follows a similar form to the previous chapter, the comparative statics are considered. The extent to which the equilibrium taxes are distorted depends on the actions of the federal government when they determine the sanction imposed if a criminal is caught and convicted. Furthermore the rich do not always benefit from becoming more mobile. After this the model is extended in a few ways to show how the equilibrium

tax rates changes depending on the assumptions underlying it. It is possible that not all the taxpayers are potential victims of crime or that there are two different groups of criminals engaging in different crimes. Finally it considers the effect of what happens when everyone pays tax.

3.1 A general model

In the previous chapter the crime considered was stealing the post tax income of a rich individual. Consider a more generic form of crime from which a criminal gains a fixed utility u if he commits the crime and is not apprehended. Let v represent the utility if he commits a crime but is caught (with $u > v$). This is a generic return from crime function as its coverage ranges from anti-social behaviour and shoplifting to murder and rape; each of these acts can be assigned a fixed level of utility depending on whether the criminal is caught. As before, assume a criminal is only able to attempt one crime during a time period. The expected utility of a criminal is thus $(1-p)u + pv$ where p is the probability a criminal is caught.

A criminal has the choice of whether to commit a crime. There is a group of n_1 potential criminals, each with a parameter ε_i, $\varepsilon_i \in [\underline{\varepsilon}, \overline{\varepsilon}]$, that represents their taste for crime. If $(1-p)u + pv \geq \varepsilon_i$ then the expected utility from crime exceeds the necessary return; ergo criminal i will commit the crime. However if $(1-p)u + pv < \varepsilon_i$ the returns from crime are not sufficient to warrant committing the crime.

It is assumed the police know the distribution of the parameter ε as well as the values of u and v so the function $q = q(p)$ represents the probability that any member of the group will attempt to participate in crime. As before the potential criminals have no taxed income. There are two jurisdictions in which people can live; criminals can only commit crime in their jurisdiction of residence. Each person has a preference for a location, represented by $x \in [0, 1]$, with a lower value signifying a preference for the domestic jurisdiction (located at 0) whilst a higher value signifies a preference for the foreign jurisdiction (located at 1). Therefore the expected utility from living in the domestic jurisdiction, for any randomly

chosen individual from the group, is $q[(1-p)u+pv]-d_1x$ whilst the individual would obtain $q^*[(1-p^*)u+p^*v]-d_1(1-x)$ from living in the foreign jurisdiction where d_1 is a measure of the group's attachment to home and an asterisk denotes the foreign jurisdiction.

There are n_2 potential victims of crime. Their utility is derived from three separate components: post tax income, locational preference and the expected loss from being a victim of crime. Each member of the group has a locational preference along the unit interval, $x \in [0,1]$, and therefore gain $-d_2x$ from living in the domestic jurisdiction but $-d_2(1-x)$ from living in the foreign jurisdiction (where d_2 is the group's attachment to home measure). For both groups the locational preferences are uniformly distributed along the unit interval. Each member of this group receives a dividend income of 1 which can be taxed by the local government. The government of the domestic jurisdiction levies a lumpsum tax of t whilst the foreign jurisdiction levies t^*. The final component of this group's utility function is the measure representing being a victim of crime. As all the individuals are risk neutral the measure is the loss of utility from being a victim of crime, z, multiplied by the probability that they are a victim of crime, $\frac{q(1-p)x_1}{x_2}$ in the domestic jurisdiction and $\frac{q(1-p)(1-x_1)}{1-x_2}$ in the foreign jurisdiction, where x_1 is the proportion of potential criminals and x_2 the proportion of potential victims living in the domestic jurisdiction. This assumes no harm occurs if a crime is attempted but the criminal is caught. Thus a randomly drawn member of this group will obtain $1-t-\frac{q(1-p)x_1}{x_2}z-d_2x$ from living in the domestic jurisdiction and $1-t^*-\frac{q(1-p)(1-x_1)}{1-x_2}z-d_2(1-x)$ in the foreign jurisdiction.

The taxes levied are used to fund a police force which helps combat crime. This occurs in two ways. The first is through p; an increase in the tax, ceteris paribus, increases the funding available for the police and allows them to catch more criminals. The second effect occurs through q; given the rise in p the expected returns from crime fall, meaning the probability that a member of the potential criminal group actually commits a crime falls. Therefore let $\frac{\partial p}{\partial t}>0$ and $\frac{\partial q}{\partial t}<0$. Further assume $\frac{\partial^2 p}{\partial t}<0$ and $\frac{\partial^2 q}{\partial t}>0$ so, in the absence of tax competition, an optimal tax can be found. These directions occur solely in relation to the tax, however the

tax base and the movement of the potential criminals also have to be considered. The total funds available for the police force are $n_2 x_2 t$ in the domestic jurisdiction and $n_2(1-x_2)t^*$ in the foreign jurisdiction. Therefore in the domestic jurisdiction p increases in x_2 whilst q decreases in x_2; these directions are reversed for the foreign jurisdiction. The movement of potential criminals also has to be considered as the more potential criminals there are in a jurisdiction the less effective a unit of funding will be. This means in the domestic jurisdiction p is decreasing in x_1 whilst q increases in it (as a potential criminal has better opportunities to hide). Again these directions are reversed for the foreign jurisdiction. Therefore in the domestic jurisdiction both the probabilities p and q are functions of t, x_1 and x_2 with $p = p\left(\frac{x_2 t}{x_1}\right)$ and $q = q\left(\frac{x_2 t}{x_1}\right)$. In the foreign jurisdiction the probabilities are $p^* = p\left(\frac{(1-x_2)t^*}{1-x_1}\right)$ and $q^* = q\left(\frac{(1-x_2)t^*}{1-x_1}\right)$.

Each jurisdiction simultaneously determines its own tax rate. After tax rates are set both potential victims and potential criminals will choose where to live. After the residency decision criminals engage in crime. The aim of the jurisdictions' governments is to maximise the non-locational utility of the potential victims of crime, aware that any change in the tax rate will affect the location decision of the two groups. Non-locational utility is defined as utility excluding the locational element. This means non-locational utility is composed of post-tax income and the expected harm caused by crime. Jurisdictions are competing to attract taxpayers, the potential victims, and repel the criminals. Therefore this chapter focuses on the Nash equilibrium tax rates. Like the previous chapter this chapter will concentrate on pure strategy Nash equilibrium tax rates that lead to symmetric outcomes.

The government of a jurisdiction does not know which of its citizens and potential migrants will commit a crime, rather it knows that each member of the potential criminal group will attempt to commit a criminal act with probability q. Consider the marginal individual located at x_1 (where the individual is indifferent between the jurisdiction in which he resides as his utility in each jurisdiction is the same after considering locational preferences). As the government of a jurisdiction is uncertain as to whether or not this marginal individual will attempt to commit a crime (as q will, in game play, take the value of zero or one), the juris-

diction has to consider the expected migration response. Thus the jurisdictions' governments will consider the marginal potential criminal to be located at x_1, where

$$q[(1-p)u+pv]-d_1x_1=q^*[(1-p^*)u+p^*v]-d_1(1-x_1) \tag{3.1}$$

and $x_1 \equiv x_1(t,t^*)$ and $x_2 \equiv x_2(t,t^*)$. As in the previous chapter, the attachment to home measure (d_1) needs to be sufficiently high in order for an interior, symmetric solution to exist. This is because at the equilibrium, the marginal increased expected return from crime (from there being an additional criminal in the jurisdiction) must be less than the marginal loss in utility due to residing in the jurisdiction which is preferred less. Equation (3.1) can be differentiated with respect to t, symmetry applied (where $t=t^*$ so $x_1=x_2=\frac{1}{2}$) and rearranged to give the equilibrium migration response of the potential criminals to a change in the domestic tax rate.

$$\left[\frac{\partial x_1}{\partial t}\right]=\frac{(4t\left[\frac{\partial x_2}{\partial t}\right]+1)\left\{[(1-p)u+pv]\left[\frac{\partial q}{\partial t}\right]-q(u-v)\left[\frac{\partial p}{\partial t}\right]\right\}}{2d_1+4t\left\{[(1-p)u+pv]\left[\frac{\partial q}{\partial t}\right]-q(u-v)\left[\frac{\partial p}{\partial t}\right]\right\}}. \tag{3.2}$$

The interaction between the movement of the two groups, taxpayers and potential criminals, is demonstrated by the equilibrium migration response of taxpayers ($\frac{\partial x_2}{\partial t}$) being present in the equilibrium migration response of the potential criminals. If the equilibrium migration response of the potential victims is positive (so a rise in the domestic tax rate attracts potential victims), the equilibrium migration response of potential criminals will be negative so long as the return from crime is not too low (given the denominator has to be positive if there is to be a symmetric equilibrium). The increase in tax attracts the rich causing more funds to be available for policing and therefore the return from crime is lowered. Similarly the equilibrium marginal response for a potential victim of crime will be characterised by the marginal individual x_2 who is indifferent between the two jurisdictions. For this individual

$$1-t-\frac{q(1-p)x_1}{x_2}z-d_2x_2=1-t^*-\frac{q^*(1-p^*)(1-x_1)}{1-x_2}z-d_2(1-x_2). \tag{3.3}$$

Again the equation can be differentiated with respect to t, symmetry applied (where $t=t^*$ so $x_1=x_2=\frac{1}{2}$) and rearranged to give the equilibrium migration response of the potential

victims to a change in the domestic tax rate.

$$\left[\frac{\partial x_2}{\partial t}\right] = \frac{-1 + (4t\left[\frac{\partial x_1}{\partial t}\right] - 1)\left\{(1-p)\left[\frac{\partial q}{\partial t}\right] - q\left[\frac{\partial p}{\partial t}\right]\right\} z - 4q(1-p)z\left[\frac{\partial x_1}{\partial t}\right]}{2d_2 + 4tz\left\{(1-p)\left[\frac{\partial q}{\partial t}\right] - q\left[\frac{\partial p}{\partial t}\right]\right\} - 4q(1-p)z}. \tag{3.4}$$

Again there is interaction between the equilibrium migration responses; the equilibrium migration response of the potential criminals affects the movement of their potential victims. Given the denominator has to be positive if there is to be a symmetric equilibrium, if the equilibrium migration response of potential criminals is positive then the equilibrium migration response of the rich is unambiguously negative. The foreign jurisdiction offers an increase in post-tax income and increased security, as fewer criminals reside there. However if the equilibrium migration response of potential criminals is negative then the direction of the equilibrium migration response of the rich is ambiguous.

Assuming $n_2 > n_1$ the government of a jurisdiction, seeking re-election, will aim to maximise the expected utility of the potential victims of crime (excluding their locational preference). Therefore the objective function for the domestic government is $\max 1 - t - \frac{q(1-p)x_1}{x_2} z$ with respect to t, remembering $x_1 \equiv x_1(t, t^*)$ and $x_2 \equiv x_2(t, t^*)$. Given the symmetry in the model the foreign government, maximising the non-locational utility of its potential victims of crime, will, in a pure strategy Nash equilibrium, levy the same tax rate. The pure strategy Nash equilibrium tax rate solves

$$-1 - z(1-p)\left[\frac{\partial q}{\partial t}\right] + qz\left[\frac{\partial p}{\partial t}\right] + 2d_2\left[\frac{\partial x_2}{\partial t}\right] = 0. \tag{3.5}$$

This follows the same functional form as the previous chapter. If tax competition is absent, so the federal government determines the tax, the optimal tax rate solves $-1 - z(1-p)\left[\frac{\partial q}{\partial t}\right] + qz\left[\frac{\partial p}{\partial t}\right] = 0$. Therefore the presence of tax competition introduces a distortion into the expression for the optimal tax. The tax is higher than optimal if $\left[\frac{\partial x_2}{\partial t}\right] > 0$ at the equilibrium whilst it is lower than optimal if $\left[\frac{\partial x_2}{\partial t}\right] < 0$ at the equilibrium.

3.1.1 Comparative statics

The properties of the pure strategy Nash equilibrium tax rate are not clearly discernable due to the complexity of the tax rate. Even when the probability functions take on a generic

linear form, for example $q = a - b\frac{x_2 t}{x_1}$ and $p = c + d\frac{x_2 t}{x_1}$, the non-linearities present difficulties. Therefore to demonstrate the properties of the equilibrium tax rate, a numerical example will be used throughout this chapter. Assume $q = 1 - \frac{3x_2 t}{2x_1}$ and $p = \frac{1}{2} + \frac{x_2 t}{2x_1}$.[1] The optimal tax (levied in the absence of tax competition) is $s = 0.167$.[2] As a base scenario assume $d_1 = d_2 = 1$, $u = 3$ and $v = -3$ so the equilibrium tax rate is $t = 0.309$.

For the optimal tax $\frac{\partial s}{\partial a} > 0$ and $\frac{\partial^2 s}{\partial a^2} = 0$. If a decreases to $\frac{4}{5}$ and $\frac{3}{5}$ then the equilibrium tax also falls to 0.286 and 0.255 respectively; whilst the equilibrium tax also increases in a it is now concave. However whilst $\frac{\partial s}{\partial b} > 0$ and $\frac{\partial^2 s}{\partial b^2} < 0$[3] if b increases to $\frac{7}{4}$ and 2 then the equilibrium tax rate reduces to 0.272 and 0.246 respectively (so $\frac{\partial t}{\partial b} < 0$ and $\frac{\partial^2 s}{\partial b^2} > 0$). The effect of tax competition is to alter the direction of both the first and second order conditions. Although the optimal tax component of (3.5) responds in the same way, the effect b has is outweighed by the effect it has on the equilibrium migration response of the taxpayers. If police expenditure per crime has no effect on the number of potential criminals, so $q = 1$ and $\frac{\partial q}{\partial t} = 0$, then the underlying model remains the same with the equilibrium tax affected by the same distortion. Thus allowing policing to have a deterrent effect does not alter the structure of the equilibrium tax rate, though it does alter the equilibrium tax that is levied.

Both $\frac{\partial s}{\partial c} < 0$ and $\frac{\partial t}{\partial c} < 0$, though $\frac{\partial^2 s}{\partial c^2} = 0$ whilst $\frac{\partial^2 t}{\partial c^2} < 0$. As c increases to $\frac{3}{5}$ and $\frac{7}{10}$ the tax rate falls to 0.198 and 0.074. Likewise both $\frac{\partial s}{\partial d} > 0$ and $\frac{\partial^2 s}{\partial d^2} < 0$ and $\frac{\partial s}{\partial d} > 0$ and $\frac{\partial^2 s}{\partial d^2} < 0$.[4] Again increasing d to $\frac{3}{5}$ and $\frac{7}{10}$ increases the equilibrium tax to 0.312 and 0.314. Although the introduction of tax competition can change the effect of the parameters on the tax rate levied, it will not necessarily alter all of the effects of a change in the parameters.

Another comparative static exercise of interest is how the equilibrium tax rate responds to an increase in the level of harm, z. It is also worth noting that z also includes the ratio of

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[1] Thus $q = \begin{cases} 1 - \frac{3x_2 t}{2x_1} & \text{if } \frac{3x_2 t}{2x_1} \leq 1 \\ 0 & \text{otherwise} \end{cases}$ and $p = \begin{cases} \frac{1}{2} + \frac{x_2 t}{2x_1} & \text{if } \frac{x_2 t}{2x_1} \leq 1 \\ 1 & \text{otherwise} \end{cases}$.

[2] In the generic form the optimal tax (the tax levied in the absence of tax competition) is $s = \frac{-1+b(1-c)z+daz}{2bdz}$.

[3] In the general case the direction of both the first and second derivatives is ambiguous; if $1 > adz$ then they are signed as in the text.

[4] In the generic case $\frac{\partial s}{\partial d} = \frac{1-b(1-c)z}{d}$ and $\frac{\partial^2 s}{\partial d^2} = \frac{-1+b(1-c)z}{d^2}$. Although the direction is ambiguous the text records the direction for the values assumed.

potential criminals to potential victims, so an increase in z represents not only an increase in the harm crime causes but also an increase in the number of potential criminals relative to the number of potential victims.[5] Reducing the value of z in units of one-fifth results in the equilibrium tax rate falling from 0.309 (when $z = 1$) to 0.286, 0.255 and 0.200 (when $z = \frac{2}{5}$). Thus the equilibrium tax is increasing and concave in z. This is the same as the optimal tax; as the disutility caused by crime increases, either from the increase in the number of potential criminals or the crime itself causes more damage, increased taxation is required as the marginal cost of crime has increased.[6]

The federal government retains control of the sanction imposed on a criminal if he is caught – it is assumed that, if caught, a criminal will be convicted. Table 3.1 gives the equilibrium tax rates as both the sanction, v, and the utility derived by a criminal if not caught, u, vary. The blank areas represent where the equilibrium tax rate does not satisfy the necessary second order conditions; it appears $|v| \geq u$ is a necessary requirement for the equilibrium tax to maximise non-locational utility of the taxpayers. For a given u the equilibrium tax rate is decreasing in the magnitude of the sanction and, furthermore, is convex in v. Recall the optimal tax is $t = 0.167$. When the sanction is low in magnitude the tax rate is higher than optimal whilst when the sanction is high in magnitude the tax rate is lower than optimal. This means it is possible for the central government to negate the distortionary effects tax competition can have by choosing an optimal sanction. Returning to equation (3.5), it is necessary that $\left[\frac{\partial x_2}{\partial t}\right] = 0$ if the optimal tax is to be levied when there is tax competition. Inserting the optimal tax into the equilibrium migration response of the potential victims to a change in the domestic tax rate yields $\left[\frac{\partial x_2}{\partial t}\right] = \frac{\pi\left[\frac{\partial x_1}{\partial t}\right]}{4d_2+\pi}$ where $\pi = 4tz\left\{(1-p)\left[\frac{\partial q}{\partial t}\right] - q\left[\frac{\partial p}{\partial t}\right]\right\} - 4q(1-p)z < 0$. Thus, in order for $\left[\frac{\partial x_2}{\partial t}\right] = 0$, $\left[\frac{\partial x_1}{\partial t}\right] = 0$ is required. Inserting the optimal tax rate into the equilibrium migration response of the potential criminals, equating to zero and rearranging yields

[5] Changing the relative number of criminals can also affect the policing production functions.

[6] For the optimal tax $\frac{\partial s}{\partial z} = \frac{1}{2bdz^2} > 0$ and $\frac{\partial^2 s}{\partial z^2} = \frac{-1}{bdz^3} < 0$.

Table 3.1: Equilibrium tax rates: changing the sanction

		v										
		-1	-2	-3	-4	-5	-6	-7	-8	-9	-10	-11	-12
u	1	0.276	0.167	0.101	0.056	0.024	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	2		0.299	0.222	0.167	0.125	0.093	0.067	0.046	0.028	0.013	0.000	0.000
	3			0.309	0.249	0.203	0.167	0.137	0.111	0.090	0.072	0.056	0.042
	4				0.315	0.267	0.227	0.194	0.167	0.143	0.122	0.104	0.089
	5					0.318	0.277	0.243	0.214	0.189	0.167	0.147	0.130
	6						0.320	0.285	0.255	0.229	0.206	0.185	0.167
	7							0.322	0.291	0.264	0.241	0.219	0.200
	8								0.323	0.296	0.272	0.250	0.230
	9									0.324	0.300	0.278	0.257
	10										0.325	0.303	0.282

$$\frac{\left[\frac{\partial p}{\partial t}\right]}{\left[\frac{\partial q}{\partial t}\right]} = \frac{(1-p)u + pv}{q(u-v)}. \tag{3.6}$$

The left-hand side of the equation is negative whilst the denominator on the right-hand side is positive. This means the numerator on the right-hand side needs to be negative if there is to be a v that ensures tax competition causes no distortion. The numerator is the expected return from committing a crime which also serves as the threshold necessary for a potential criminal to determine whether or not to commit a crime. In order for there to be a sanction which results in the optimal tax being levied after tax competition, the outside options of the potential criminals have to be negative. In the numerical example being used here the optimal sanction, from the tax competition viewpoint, is $v = -2u$. Although not present in the numerical example, a change in v will also affect q as it lowers the expected return from crime, ceteris paribus. However as an increase in v would increase b, this reinforces the reduction caused to the equilibrium tax. It is interesting to note that the optimal punishment is totally independent of the harm caused by crime. Also it assumes the punishment can be expressed in monetary terms and that, like Becker (1968), the punishment is costless for taxpayers.[7]

Proposition 6 *The federal government is able to negate the effects of tax competition on the*

[7]The previous chapter showed that when the punishment is not socially costless the response of taxpayers is to prefer less policing in order to fund fewer prisons as the cost of imprisonment rises whilst tax competition introduced the same distortion into the equilibrium tax of the rich.

equilibrium tax rate if crime is still committed when the expected return from crime is negative and the sanction is socially costless.

The final comparative statics exercise relates to the attachment to home measures. The greater the attachment to home, the lower the mobility of the group as the locational element of utility plays a greater role in the residency decision. Inserting the optimal tax into (3.4) the equilibrium migration response of potential victims to a change in the domestic tax is $\left[\frac{\partial x_2}{\partial t}\right] = \frac{\pi\left[\frac{\partial x_1}{\partial t}\right]}{4d_2+\pi}$, where $\pi = 4tz\left\{(1-p)\left[\frac{\partial q}{\partial t}\right] - q\left[\frac{\partial p}{\partial t}\right]\right\} - 4q(1-p)z < 0$. When this is substituted into the equilibrium migration response of potential criminals at the equilibrium tax rate it gives $\left[\frac{\partial x_1}{\partial t}\right] = \frac{\varpi\left(1+4t\left[\frac{\partial x_1}{\partial t}\right]\right)}{2d_1+4t\varpi}$, where $\varpi = 4t\left\{[(1-p)u+pv]\left[\frac{\partial q}{\partial t}\right] - q(u-v)\left[\frac{\partial p}{\partial t}\right]\right\}$. The direction of ϖ is ambiguous as the expected return from crime can be either positive or negative. Thus the equilibrium migration response of taxpayers to a change in the tax rate (at the equilibrium tax) is $\left[\frac{\partial x_2}{\partial t}\right] = \frac{\pi\varpi}{4d_2(2d_1+4t\varpi)+2\pi d_1}$. The distortion in the tax rate when compared to the optimum, $\Delta = d_2\frac{\partial x_2}{\partial t}$, has the properties $\frac{\partial\Delta}{\partial d_1} = \frac{-2\pi\varpi(4d_2-\pi)}{[4d_2(2d_1+4t\varpi)+2\pi d_1]^2}$ and $\frac{\partial\Delta}{\partial d_2} = \frac{2\pi^2\varpi d_1}{[4d_2(2d_1+4t\varpi)+2\pi d_1]^2}$.

Taking $\frac{\partial\Delta}{\partial d_2}$ first, the distortion is decreasing in d_2 if $\varpi < 0$ whilst it is increasing in d_2 if $\varpi > 0$. Thus the equilibrium tax is decreasing in d_2 if $\varpi < 0$; if $\varpi < 0$ then a reduction in d_2 increases Δ so a greater tax is needed for (3.5) to hold. Assume $\varpi < 0$ then if $4d_2(2d_1+4t\varpi)+2\pi d_1 < 0$ the equilibrium tax will move towards the optimal tax as the rich become more mobile whilst if $4d_2(2d_1+4t\varpi)+2\pi d_1 > 0$ the tax will be decreasing below the optimal tax as the rich become more mobile. Returning to the numerical example assume d_1 remains constant (with $d_1 = 1$) but d_2 increases in steps of 0.2. The equilibrium tax reduces in value from 0.309 (when $d_2 = 1$) to 0.305, 0.301, 0.297, 0.293 and 0.290 (when $d_2 = 2$). This runs counter to expectations and the tax competition literature which suggests capital becomes harder to tax as it becomes more mobile and therefore the resulting equilibrium taxes approach the optimal tax for the capital's owners. Although the equilibrium tax will be increasing in d_2 if $\varpi > 0$, it will move away from the optimal tax if $4d_2(2d_1+4t\varpi)+2\pi d_1 > 0$ with too many resources flowing towards the police. Thus if $4d_2(2d_1+4t\varpi)+2\pi d_1 < 0$ and ϖ possess the same direction then any decrease in d_2 will move the equilibrium tax further away

from the optimum. When the capital owners benefit from the tax receipts an increase in their mobility can move the resulting equilibrium tax further from the optimum and consequently the taxpayers become overly secure.

Proposition 7 *The equilibrium tax rate can diverge from the optimum tax rate for the rich as they become more mobile.*

Likewise $\frac{\partial \Delta}{\partial d_1} = \frac{-2\pi\varpi(4d_2-\pi)}{[4d_2(2d_1+4t\varpi)+2\pi d_1]^2}$ means the equilibrium tax will be increasing in d_1 if $2\pi\varpi(4d_2 - \pi) < 0$ or decreasing in it if the inequality does not hold. Thus as potential criminals become more mobile the equilibrium tax will rise if $2\pi\varpi(4d_2 - \pi) > 0$; as for d_2 the reduction in d_1 increases Δ causing the equilibrium tax rate to rise. In the numerical example if d_1 increases in 0.2 steps whist $d_2 = 1$ remains constant then the equilibrium tax rate reduces from 0.309 (when $d_1 = 1$) to 0.303, 0.299, 0.296, 0.294 and 0.291 (when $d_1 = 2$). As potential criminals are less mobile their equilibrium migration response to a change in the tax rate is lessened and consequently so is the equilibrium migration response of the potential victims. Thus the reduced mobility of potential criminals allows the equilibrium tax to be reduced without attracting criminals to a jurisdiction. However it is possible, if $2\pi\varpi(4d_2 - \pi) < 0$, for the equilibrium tax rate to fall as potential criminals become more mobile.

The base model again demonstrates that when a jurisdiction's government chooses to maximise the non-locational utility of its residents, the equilibrium tax will be distorted by the equilibrium migration response of taxpayers. If an increase in the tax rate will attract more taxpayers at the equilibrium then there will be overtaxation. Conversely if it causes residents to leave then there will be undertaxation. This base model demonstrates two interesting features of tax competition when the receipts are used to increase the security of the capital's owners. The first is that under certain circumstances a federal government, when determining a sanction, has the ability to ensure tax competition does not result in non-optimal tax rates being levied. The second feature is that the tax rate can move away from the optimum tax as the capital becomes more mobile – an increase in the taxpayers' mobility can make taxpayers worse off.

3.2 Policing as a good

In the previous section the probability of catching a criminal was a function of the total funding available to the police and the number of potential suspects – in essence it represented the detection role of the police. There are two alternatives to this. The first is to assume policing is a public good, so the whole police force is focused on the preventative role and thus their visibility reduces the opportunities available to criminals. Therefore let $p = p(x_2 t)$, $q = q(x_2 t)$, $p^* = p((1-x_2)t^*)$ and $q^* = q((1-x_2)t^*)$. For potential criminals equation (3.1) still represents the marginal individual who is indifferent between the two jurisdictions. Therefore the equilibrium migration response for a potential criminal to a change in the domestic tax rate can be found in the same way as before and is given by

$$\left[\frac{\partial x_1}{\partial t}\right] = \frac{(4t\left[\frac{\partial x_2}{\partial t}\right] + 1)\left\{[(1-p)u + pv]\left[\frac{\partial q}{\partial t}\right] - q(u-v)\left[\frac{\partial p}{\partial t}\right]\right\}}{2d_1}. \tag{3.7}$$

The direction of the equilibrium migration response remains ambiguous. However comparing this equilibrium migration response to the one in the base model, (3.2), the only difference is the denominator. The crowding effect of potential criminals in the base model decreased the value of the denominator and thus heightened the response to any change in the domestic tax rate – if those who are close to indifferent regarding their preferred location leave a jurisdiction then those that remain, in the base model, would have an increased probability of being arrested which could force them to move. In the public good model this second round effect disappears.

For potential victims equation (3.3) still represents the marginal individual who is indifferent between the two jurisdictions. Thus the equilibrium migration response for a potential victim to a change in the domestic tax rate can be found in a similar way, meaning

$$\left[\frac{\partial x_2}{\partial t}\right] = \frac{-2 - z(1-p)\left[\frac{\partial q}{\partial t}\right] + qz\left[\frac{\partial p}{\partial t}\right] - 8q(1-p)z\left[\frac{\partial x_1}{\partial t}\right]}{4d_2 + 4tz\left\{(1-p)\left[\frac{\partial q}{\partial t}\right] - q\left[\frac{\partial p}{\partial t}\right]\right\} - 8q(1-p)z}. \tag{3.8}$$

As usual there is interaction between the movement between the two groups. Comparing the public good model with the base model, (3.4), both the numerator and the denominator have changed. For a given t changing policing to a public good increases the denominator. The

change in policing also reduces the role of the equilibrium migration response of potential criminals in determining the equilibrium migration response of taxpayers, however it still enters negatively in the equilibrium migration response of taxpayers.

The pure strategy Nash equilibrium tax rate, given the jurisdiction's objective function of maximising the non-locational utility of taxpayers, $\max 1 - t - \frac{q(1-p)x_1}{x_2}z$, solves

$$-2 - z(1-p)\left[\frac{\partial q}{\partial t}\right] + qz\left[\frac{\partial p}{\partial t}\right] + 4d_2\left[\frac{\partial x_2}{\partial t}\right] = 0. \tag{3.9}$$

This follows the same form as the base model, (3.5). The change in the coefficients stems from the absence of criminals from the policing production function – in the previous section $p = p\left(\frac{x_2 t}{x_1}\right) = p(t)$ at the equilibrium whereas in this model $p = p(x_2 t) = p\left(\frac{1}{2}t\right)$. However there is no difference to the overall structure with the equilibrium tax distorted from the optimal tax by the equilibrium migration response of the taxpayers. Returning to the numerical example the equilibrium tax when policing is a public good is 0.285.

An alternative way of considering policing is that it provides a private good to the individuals who pay tax – each potential victim of crime receives the same level of security irrespective of the total number of either potential victims or criminals. Therefore the probability functions in the domestic jurisdiction become $p = p(t)$ and $q = q(t)$. Equation (3.1) still represents the marginal potential criminal indifferent between the two jurisdictions so the equilibrium migration response of a potential criminal to a change in the domestic tax rate is given by

$$\left[\frac{\partial x_1}{\partial t}\right] = \frac{[(1-p)u + pv]\left[\frac{\partial q}{\partial t}\right] - q(u-v)\left[\frac{\partial p}{\partial t}\right]}{2d_1}. \tag{3.10}$$

Again the equilibrium migration response of criminals to a change in the domestic tax rate is ambiguous unless the expected return from crime is positive (in which case the response will be negative as the increase in tax reduces both the expected return from crime and the probability of being a criminal). Further the equilibrium migration response of potential victims is absent as there are no size effects to policing, so it makes no difference whether the tax rate attracts or repels the potential victims. Equation (3.3) still represents the marginal potential victim who is indifferent between the two jurisdictions so the equilibrium migration

response of a potential victim to a change in the domestic tax rate is

$$\left[\frac{\partial x_2}{\partial t}\right] = \frac{-1 - z(1-p)\left[\frac{\partial q}{\partial t}\right] + qz\left[\frac{\partial p}{\partial t}\right] - 4qz(1-p)\left[\frac{\partial x_1}{\partial t}\right]}{2d_2 - 4q(1-p)z}. \tag{3.11}$$

The direction of the equilibrium migration response of taxpayers also remains ambiguous. The presence of the equilibrium migration response of potential criminals remains as an increase in their number lowers the utility of taxpayers (due to the increase in the probability that they become a potential victim). In comparison with the base model, (3.4), the denominator is larger, as the movement of other taxpayers has no effect on security, whilst the numerator can be either smaller or larger (depending on the direction of the equilibrium migration response of potential criminals in the base model).

The pure strategy Nash equilibrium tax rate solves

$$-1 - z(1-p)\left[\frac{\partial q}{\partial t}\right] + qz\left[\frac{\partial p}{\partial t}\right] + 2d_2\left[\frac{\partial x_2}{\partial t}\right] = 0. \tag{3.12}$$

This equation is the same as (3.5), however the equilibrium migration responses are different, (3.10) and (3.11), therefore the resulting equilibrium tax rate is different. Using the numerical example, the equilibrium tax if policing is a private good is 0.271.

In the numerical examples the equilibrium tax in the base model is the highest whilst it is lowest when policing is a private good. However the optimal punishment remains the same in all three scenarios so for the optimal value of v the same tax is levied irrespective of the type of good policing is. However if the sanction is harsher than optimal the highest tax is levied when policing is a private good and the lowest tax in the base model. Therefore there is no uniform ordering of the tax rates depending on the type of good policing is. However the type that it is will influence the tax that is levied.

3.3 Victimised groups

So far it has been assumed that everyone can be a potential victim of crime. For certain classes of crime certain groups are targeted, for example racist or homophobic crime. This can be reflected in the model by introducing a third group of individuals of size n_3 who are

neither potential criminals nor potential victims of crime. This group does, however, receive a dividend income of one (like the potential victims) and therefore has to pay tax. It is also assumed that their locational preferences are uniformly distributed along the unit interval. Let the ratio of non-potential victims to potential victims be $\lambda = \frac{n_3}{n_2}$ so the probabilities can be written as $p = p\left(\frac{x_2 t + \lambda x_3 t}{x_1}\right)$ and $q = q\left(\frac{x_2 t + \lambda x_3 t}{x_1}\right)$ for the domestic jurisdiction. The equilibrium migration response of potential criminals can be found in the same way as before giving an equilibrium migration response to a change in the domestic tax rate of

$$\left[\frac{\partial x_1}{\partial t}\right] = \frac{(4t\left[\frac{\partial x_2}{\partial t}\right] + 4\lambda t\left[\frac{\partial x_3}{\partial t}\right] + 1 + \lambda)\left\{[(1-p)u + pv]\left[\frac{\partial q}{\partial t}\right] - q(u-v)\left[\frac{\partial p}{\partial t}\right]\right\}}{2d_1 + 4t(1+\lambda)\left\{[(1-p)u + pv]\left[\frac{\partial q}{\partial t}\right] - q(u-v)\left[\frac{\partial p}{\partial t}\right]\right\}} \tag{3.13}$$

whilst the equilibrium migration response of the potential victims of crime to a change in the domestic tax rate is given by

$$\left[\frac{\partial x_2}{\partial t}\right] = \frac{-1 + [4t(1+\lambda)\left[\frac{\partial x_1}{\partial t}\right] - 4\lambda t\left[\frac{\partial x_3}{\partial t}\right] - 1 - \lambda]Az - 4q(1-p)z\left[\frac{\partial x_1}{\partial t}\right]}{2d_2 + 4tzA - 4q(1-p)z} \tag{3.14}$$

where $A = (1-p)\left[\frac{\partial q}{\partial t}\right] - q\left[\frac{\partial p}{\partial t}\right]$. These follow the same form as before, with $\left[\frac{\partial x_3}{\partial t}\right]$ featuring in the same way as $\left[\frac{\partial x_2}{\partial t}\right]$ in (3.13) as they both change the tax base in the same way. In $\left[\frac{\partial x_2}{\partial t}\right]$ the equilibrium migration response of this third group, if positive, increases the value of the numerator and therefore increases the equilibrium migration response of the potential victims. If it is negative, then it lowers the equilibrium migration response for potential victims. For the new group of individuals the equilibrium migration response will be characterised by the marginal individual x_3 who is indifferent between the two jurisdiction, satisfying

$$1 - t - d_3 x_3 = 1 - t^* - d_3(1 - x_3) \tag{3.15}$$

This assumes the third group is not even indirectly affected by the crime; the presence of other people being subject to criminal attacks does not feature in their utility. The equilibrium response to a change in the domestic tax rate is

$$\left[\frac{\partial x_3}{\partial t}\right] = \frac{-1}{2d_3} \tag{3.16}$$

For once the direction of the response is unambiguous. An increase in the tax rate repels this group as it lowers their utility without generating any corresponding change to their level of security.

The government of a jurisdiction has an interesting choice concerning its objective function. If the crime is perpetrated against a minority, so $n_3 > n_2$, then the government seeking re-election would choose $\max 1 - t$ so $t = 0$. As the median voter gains no utility from crime reduction the government will not tax to fund it. This leaves the victimised minority, which is prepared to pay for a reduced level of crime, to suffer. This result is not due to tax competition – in a single jurisdiction world a government seeking re-election will not levy a tax if the median voter is not prepared to pay it.

An alternative objective function could include the crime. The federal government could place a requirement on jurisdictional governments to include the crime when determining their tax rate and specify a minimum weight that has to be attached to it, γ. The objective function for the domestic jurisdiction is $\max 1 - t - \gamma \frac{q(1-p)x_1}{x_2} z$. The resulting symmetric pure strategy Nash equilibrium tax rate solves

$$\gamma - 2 - \gamma(1+\lambda)\left[(1-p)\left[\frac{\partial q}{\partial t}\right] - q\left[\frac{\partial p}{\partial t}\right]\right] z + 2d_2\gamma\left[\frac{\partial x_2}{\partial t}\right] = 0 \qquad (3.17)$$

Comparing this to the base model, (3.5), if $\gamma = 1$ and $\lambda = 0$ then the same equilibrium tax results as all the taxpayers are potential victims of crime and therefore the objective function becomes the same as before. If the value of γ falls, so the crime has a lower weight in the objective function, then the equilibrium tax rate will also fall in the absence of tax competition. As $\left[\frac{\partial x_2}{\partial t}\right]$ is independent of γ, if $\left[\frac{\partial x_2}{\partial t}\right] < 0$ then the tax rate will fall as γ falls. If $\left[\frac{\partial x_2}{\partial t}\right] > 0$ then the equilibrium tax can either increase or decrease in response to a decrease in γ. However if the value of λ increases then the equilibrium tax rate will fall in the absence of tax competition. However as λ enters $\left[\frac{\partial x_2}{\partial t}\right]$ the effect of a change in λ on the equilibrium tax is not easy to discern.

Table 3.2 shows the equilibrium tax rate using the same numerical model as in the base case but allowing γ and λ to vary. The table assumes $b = \frac{3}{2(1+\lambda)}$ and $d = \frac{1}{2(1+\lambda)}$ so p and q are independent of λ. The columns represent the proportion of potential victims as a percentage of the total taxpaying population. If $n_3 < n_2$ (so $\lambda < 1$ or $(1+\lambda)^{-1} > 0.5$), so the victimised group is the majority group, then the jurisdictions' governments will set

Table 3.2: Equilibrium tax rates: changing the proportion of potential victims

		$\frac{100}{(1+\lambda)}$ 5	10	20	30	40	50	60	70	80	90	95
γ	0.1	0.086	0.108	0.162	0.201	0.228	0.248	0.264	0.277	0.289	0.299	0.303
	0.2	0.143	0.160	0.190	0.215	0.236	0.252	0.267	0.279	0.290	0.299	0.304
	0.3	0.173	0.185	0.207	0.226	0.242	0.257	0.269	0.281	0.291	0.300	0.304
	0.4	0.192	0.201	0.218	0.234	0.248	0.261	0.272	0.282	0.292	0.300	0.304
	0.5	0.206	0.214	0.228	0.241	0.253	0.264	0.275	0.284	0.293	0.301	0.305
	0.6	0.217	0.224	0.236	0.247	0.258	0.266	0.277	0.286	0.294	0.301	0.305
	0.7	0.227	0.232	0.242	0.252	0.262	0.271	0.279	0.287	0.295	0.302	0.305
	0.8	0.235	0.239	0.248	0.257	0.265	0.273	0.281	0.289	0.296	0.302	0.306
	0.9	0.242	0.246	0.254	0.261	0.269	0.276	0.283	0.290	0.297	0.303	0.306
	1.0	0.248	0.252	0.259	0.265	0.272	0.279	0.285	0.291	0.298	0.303	0.306

$\gamma = 1$ according to the wishes of the median voter and no other values of γ are applicable. If $n_3 > n_2$ (so $\lambda > 1$ or $(1+\lambda)^{-1} < 0.5$), so the victimised group is the minority group, then the jurisdictions' governments will use the level of γ specified by the government. The properties of the equilibrium tax rate are as expected. The tax rate increases in γ but decreases in λ. As a greater weight is placed on the crime in the objective function of the jurisdiction's government, the greater the equilibrium tax rate to lower the crime level. Likewise the higher the proportion of potential victims in the population (akin to a lower value of λ) the higher the tax rate as the movement of the third group has a reduced effect on the overall tax yield. In the absence of tax competition a tax will only be levied if $\gamma > \frac{4}{5}$; however if $\gamma = 1$ the optimal tax for potential victims is levied ($t = 0.167$). Even for low values of γ the presence of tax competition causes a tax to be levied which is higher than optimal. When all taxpayers were potential victims of crime it was possible for there to be over taxation compared to the optimal. This feature does not disappear if only a minority of the population is affected by the crime; tax competition can result in too much security being provided.

Proposition 8 *A minority subjected to crime will not necessarily loose out when police forces compete in taxes as long as the crime enters the local jurisdictions' objective function.*

An alternative explanation for γ is that non-potential victims also care about the level of crime in a jurisdiction and therefore include the level of crime in their utility function.

Table 3.3: Equilibrium tax rates: changing the proportion of potential victims

		$\frac{100}{(1+\lambda)}$										
		5	10	20	30	40	50	60	70	80	90	95
γ	0.1	0.137	0.157	0.194	0.220	0.240	0.256	0.269	0.281	0.291	0.300	0.304
	0.2	0.201	0.211	0.228	0.243	0.255	0.267	0.277	0.285	0.294	0.301	0.305
	0.3	0.232	0.238	0.248	0.258	0.267	0.275	0.283	0.290	0.296	0.302	0.305
	0.4	0.252	0.256	0.263	0.270	0.276	0.282	0.288	0.293	0.299	0.304	0.306
	0.5	0.267	0.269	0.275	0.279	0.284	0.288	0.293	0.297	0.301	0.305	0.307
	0.6	0.279	0.280	0.284	0.287	0.291	0.294	0.297	0.300	0.303	0.306	0.307
	0.7	0.288	0.289	0.292	0.294	0.296	0.298	0.300	0.303	0.305	0.307	0.308
	0.8	0.296	0.297	0.298	0.300	0.301	0.302	0.304	0.305	0.306	0.308	0.308
	0.9	0.303	0.304	0.304	0.305	0.305	0.306	0.307	0.307	0.308	0.308	0.309
	1.0	0.309	0.309	0.309	0.309	0.309	0.309	0.309	0.309	0.309	0.309	0.309

Therefore the equilibrium migration response of the third group will now be characterised by the marginal individual x_3 who is indifferent between the two jurisdictions, so

$$1 - t - \gamma \frac{q(1-p)x_1}{x_2} z - d_3 x_3 = 1 - t^* - \gamma \frac{q^*(1-p^*)(1-x_1)}{1-x_2} z - d_3(1-x_3). \tag{3.18}$$

The equilibrium migration response of this group to a change in the domestic tax rate is

$$\left[\frac{\partial x_3}{\partial t}\right] = \frac{-1 - \gamma z[4t\left[\frac{\partial x_2}{\partial t}\right] + (1+\lambda)(1 - 4t\left[\frac{\partial x_1}{\partial t}\right])]A - 4\gamma z q(1-p)(\left[\frac{\partial x_1}{\partial t}\right] - \left[\frac{\partial x_2}{\partial t}\right])}{2d_3 + 4\lambda t \gamma A} \tag{3.19}$$

where $A = (1-p)\left[\frac{\partial q}{\partial t}\right] - q\left[\frac{\partial p}{\partial t}\right]$. The pure strategy Nash equilibrium is the tax rate that solves (3.17), with (3.13), (3.14) and (3.19) being the equilibrium migration responses. Table 3.3 gives the equilibrium tax rates for the base model, but allowing γ and λ to vary. The properties of the equilibrium tax are very similar to those when crime was excluded from the utility function. The equilibrium tax is increasing in γ but decreasing in λ (apart from when $\gamma = 1$ where the non-victims behave like victims). As the non-victims now care about the level of crime in the jurisdiction the equilibrium tax rates are higher than those levied when they did not care, for all γ and λ. However this means too many resources are still devoted to crime reduction.

Thus when the crime is perpetrated against a minority, even though the majority of the taxpaying population is not affected and will leave a jurisdiction if it levies a higher tax than the other, the possibility of over taxation compared to the optimal remains; victimised minority groups will not automatically loose out in the competition so long as the harm caused

by the crime is in the jurisdiction's objective function. The numerical example suggests the equilibrium tax is increasing in both the victimised groups size as a proportion of the taxpaying population and the weight attached to their suffering in the objective function.

3.4 Two crimes

In the previous section it was assumed there were two groups of taxpayers but only one crime. This section reverses these numbers so we return to there only being one group of taxpayers but now there are two crimes they can be the victim of. Let the first crime be denoted by $\dot{}$ and the second crime by $\ddot{}$. Further, each crime is committed by a separate group of criminals, so there are three groups that need to be considered. Assume the crimes are sufficiently different in nature so there are no spillovers in policing a crime; any funds allocated to policing one crime has no effect on the other. Consequently the police have to determine what proportion of their funds to allocate to fighting each crime as well as which tax rate to levy. Let η denote the proportion of funds allocated to crime 1 whilst $1-\eta$ denotes the proportion allocated to crime 2. Thus in the domestic jurisdiction the probabilities for the first crime are $\dot{p} = \dot{p}\left(\frac{\eta x_2 t}{x_1}\right)$ and $\dot{q} = \dot{q}\left(\frac{\eta x_2 t}{x_1}\right)$ whilst for the second crime $\ddot{p} = \ddot{p}\left(\frac{(1-\eta) x_2 t}{x_1}\right)$ and $\ddot{q} = \ddot{q}\left(\frac{(1-\eta) x_2 t}{x_1}\right)$. This section firstly allows the jurisdiction to compete in t with η determined at the federal level. This is then reversed so jurisdictions are free to determine their value of η whilst t is determined federally.

Firstly assume the jurisdictions compete in taxes whilst the value of η is determined by the federal government. The equilibrium migration response of the first group of criminals to a change in the domestic tax rate is

$$\left[\frac{\partial \dot{x}_1}{\partial t}\right] = \frac{\eta(4t\left[\frac{\partial x_2}{\partial t}\right]+1)\left\{[(1-\dot{p})\dot{u}+\dot{p}\dot{v}]\left[\frac{\partial \dot{q}}{\partial t}\right]-\dot{q}(\dot{u}-\dot{v})\left[\frac{\partial \dot{p}}{\partial t}\right]\right\}}{2\dot{d}_1+4\eta t\left\{[(1-\dot{p})\dot{u}+\dot{p}\dot{v}]\left[\frac{\partial \dot{q}}{\partial t}\right]-\dot{q}(\dot{u}-\dot{v})\left[\frac{\partial \dot{p}}{\partial t}\right]\right\}} \tag{3.20}$$

whilst for the second group

$$\left[\frac{\partial \ddot{x}_1}{\partial t}\right] = \frac{(1-\eta)(4t\left[\frac{\partial x_2}{\partial t}\right]+1)\left\{[(1-\ddot{p})\ddot{u}+\ddot{p}\ddot{v}]\left[\frac{\partial \ddot{q}}{\partial t}\right]-\ddot{q}(\ddot{u}-\ddot{v})\left[\frac{\partial \ddot{p}}{\partial t}\right]\right\}}{2\ddot{d}_1+4(1-\eta t)\left\{[(1-\ddot{p})\ddot{u}+\ddot{p}\ddot{v}]\left[\frac{\partial \ddot{q}}{\partial t}\right]-\ddot{q}(\ddot{u}-\ddot{v})\left[\frac{\partial \ddot{p}}{\partial t}\right]\right\}}. \tag{3.21}$$

These follow the same form as before, as too does the equilibrium migration response of

Table 3.4: Equilibrium tax rates: two crimes, competing in t

		η										
		0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0
$\ddot{z}$	1.0	0.083	0.116	0.184	0.767	0.579	0.496	0.453	0.430	0.412	0.380	0.329
	1.5	0.069	0.090	0.125	0.199	0.468	0.436	0.421	0.417	0.412	0.406	0.344
	2.0	0.043	0.053	0.076	0.108	0.172	0.302	0.358	0.382	0.409	0.438	0.367
	2.5	0.013	0.021	0.032	0.050	0.080	0.141	0.252	0.324	0.375	0.465	0.431
	3.0	0.000	0.000	0.000	0.002	0.017	0.047	0.117	0.242	0.323	0.444	0.441

taxpayers to a change in the domestic tax:

$$\left[\frac{\partial x_2}{\partial t}\right] = \frac{\eta(4t\left[\frac{\partial \dot{x}_1}{\partial t}\right] - 1)\dot{z}A - B\dot{z}\left[\frac{\partial \dot{x}}{\partial t}\right] + (1-\eta)(4t\left[\frac{\partial \ddot{x}_1}{\partial t}\right] - 1)\ddot{z}C - D\ddot{z}\left[\frac{\partial \ddot{x}_1}{\partial t}\right]}{2d_2 + 4\eta t\dot{z}A - B + 4(1-\eta)t\ddot{z}C - D} \tag{3.22}$$

where $A = (1-\dot{p})\left[\frac{\partial \dot{q}}{\partial t}\right] - \dot{q}\left[\frac{\partial \dot{p}}{\partial t}\right]$, $B = 4\dot{q}(1-\dot{p})$, $C = (1-\ddot{p})\left[\frac{\partial \ddot{q}}{\partial t}\right] - \ddot{q}\left[\frac{\partial \ddot{p}}{\partial t}\right]$ and $D = 4\ddot{q}(1-\ddot{p})$.

The pure strategy Nash equilibrium tax rate levied by both jurisdictions solves

$$-1-\dot{z}\eta(1-\dot{p})\left[\frac{\partial \dot{q}}{\partial t}\right]+\dot{z}\eta\dot{q}\left[\frac{\partial \dot{p}}{\partial t}\right]-\ddot{z}(1-\eta)(1-\ddot{p})\left[\frac{\partial \ddot{q}}{\partial t}\right]+\ddot{z}(1-\eta)\ddot{q}\left[\frac{\partial \ddot{p}}{\partial t}\right]+2d_2\left[\frac{\partial x_2}{\partial t}\right] = 0. \tag{3.23}$$

This follows the same form as previous expressions – the optimal tax plus the potentially distorting equilibrium migration response of taxpayers. Returning to the numerical example assume both crimes have similar probability functions, so $\dot{q} = 1 - \frac{3\theta x_2 t}{2\dot{x}_1}$, $\ddot{q} = 1 - \frac{3(1-\theta)x_2 t}{2\ddot{x}_1}$, $\dot{p} = \frac{1}{2} + \frac{\theta x_2 t}{2\dot{x}_1}$ and $\ddot{p} = \frac{1}{2} + \frac{(1-\theta)x_2 t}{2\ddot{x}_1}$. The utility gained from either crime being successful is 3 whilst the sanction for both crimes is -3. Finally the harm caused by both crimes is 2. Allowing η to vary between 0 and 1 in units of 0.1 gives equilibrium taxes of: 0.250, 0.273, 0.300, 0.324, 0.339, 0.344, 0.339, 0.324, 0.300, 0.273 and 0.250. Given the symmetry between the crimes, the equilibrium tax rate is symmetric and decreasing around $\eta = \frac{1}{2}$. When the values of the other variables are changed the bell shaped curve remains, though the peak shifts. Table 3.4 allows the values of the equilibrium tax when $\dot{z} = 1$, $\ddot{v} = -9$ and $\ddot{z}$ varies. The table also shows how the equilibrium tax is decreasing in $\ddot{z}$. The tax is also decreasing in the attachment to home measure of the criminals but increasing in the attachment to home measure of the taxpayers. Finally as the sanction becomes more severe or criminals derive less utility from a successful crime, the equilibrium tax rate falls. This assumes η is fixed by the federal government.

An alternative is the federal government determines the value of t but the jurisdictions are

able to determine their own values of η. The equilibrium migration response of the first group of criminals to a change in the proportion of funds spent fighting crime is given by

$$\left[\frac{\partial \dot{x}_1}{\partial \eta}\right] = \frac{(4\eta t\left[\frac{\partial x_2}{\partial \eta}\right] + t)\left\{[(1-\dot{p})\dot{u} + \dot{p}\dot{v}]\left[\frac{\partial \dot{q}}{\partial \eta}\right] - \dot{q}(\dot{u}-\dot{v})\left[\frac{\partial \dot{p}}{\partial \eta}\right]\right\}}{2\dot{d}_1 + 4\eta t\left\{[(1-\dot{p})\dot{u} + \dot{p}\dot{v}]\left[\frac{\partial \dot{q}}{\partial \eta}\right] - \dot{q}(\dot{u}-\dot{v})\left[\frac{\partial \dot{p}}{\partial \eta}\right]\right\}}. \tag{3.24}$$

Likewise the equilibrium migration response of the second group of criminals to a change in the proportion of funding is

$$\left[\frac{\partial \ddot{x}_1}{\partial \eta}\right] = \frac{[4(1-\eta)t\left[\frac{\partial x_2}{\partial \eta}\right] - t]\left\{[(1-\ddot{p})\ddot{u} + \ddot{p}\ddot{v}]\left[\frac{\partial \ddot{q}}{\partial \eta}\right] - \ddot{q}(\ddot{u}-\ddot{v})\left[\frac{\partial \ddot{p}}{\partial \eta}\right]\right\}}{2\ddot{d}_1 + 4(1-\eta)t\left\{[(1-\ddot{p})\ddot{u} + \ddot{p}\ddot{v}]\left[\frac{\partial \ddot{q}}{\partial \eta}\right] - \ddot{q}(\ddot{u}-\ddot{v})\left[\frac{\partial p}{\partial \eta}\right]\right\}}. \tag{3.25}$$

The equilibrium migration response of the taxpayers to a change in the proportion of funds allocated to fighting crime one is given by

$$\left[\frac{\partial x_2}{\partial \eta}\right] = \frac{(4\eta t\left[\frac{\partial \dot{x}_1}{\partial \eta}\right] - t)\dot{z}A - B\dot{z}\left[\frac{\partial \dot{x}}{\partial \eta}\right] + (4(1-\eta)t\left[\frac{\partial \ddot{x}_1}{\partial \eta}\right] - 1)\ddot{z}C - D\ddot{z}\left[\frac{\partial \ddot{x}_1}{\partial \eta}\right]}{2d_2 + 4\eta t\dot{z}A - B + 4(1-\eta)t\ddot{z}C - D} \tag{3.26}$$

where $A = (1-\dot{p})\left[\frac{\partial \dot{q}}{\partial \eta}\right] - \dot{q}\left[\frac{\partial \dot{p}}{\partial \eta}\right]$, $B = 4\dot{q}(1-\dot{p})$, $C = (1-\ddot{p})\left[\frac{\partial \ddot{q}}{\partial \eta}\right] - \ddot{q}\left[\frac{\partial \ddot{p}}{\partial \eta}\right]$ and $D = 4\ddot{q}(1-\ddot{p})$. These have similar forms to the previous expressions. The pure strategy Nash equilibrium is given by the proportion that solves

$$-\dot{z}t(1-\dot{p})\left[\frac{\partial \dot{q}}{\partial \eta}\right] + \dot{z}t\dot{q}\left[\frac{\partial \dot{p}}{\partial \eta}\right] - \ddot{z}t(1-\ddot{p})\left[\frac{\partial \ddot{q}}{\partial \eta}\right] + \ddot{z}t\ddot{q}\left[\frac{\partial \ddot{p}}{\partial \eta}\right] + 2d_2\left[\frac{\partial x_2}{\partial \eta}\right] = 0. \tag{3.27}$$

The equilibrium migration response of taxpayers is again present when the choice regarding η is left to the jurisdictions. This term again disappears when η is determined at the federal level. Therefore structurally there is little difference between whether jurisdictions compete in t or η; competition between the jurisdictions will mean policing resources can potentially be suboptimal.

Returning to the numerical example, the equilibrium value of η responds, in the majority of cases, in the manner expected. If there is perfect symmetry between the two crimes then the equilibrium allocation is undistorted with $\eta = \frac{1}{2}$. If one group of criminals becomes more mobile relative to the other then an increased proportion of the total funds is spent fighting that crime. If $\ddot{d}_1 = 1$ then increasing $\dot{d}_1$ in units of $\frac{2}{5}$ from $\dot{d}_1 = \frac{1}{5}$ gives equilibrium values of 0.631, 0.562, 0.500, 0.448 and 0.406. In comparison altering the value of d_2 has no effect on η. If the policing technologies available for each crime are different then η tends in general

towards the more ineffective technology. Thus if $\dot{a} < \ddot{a}$, $\dot{b} > \ddot{b}$ or $\dot{c} > \ddot{c}$ then $\eta < \frac{1}{2}$; however if $\dot{d} < \ddot{d}$ then $\eta < \frac{1}{2}$ also. Another oddity occurs if the harm done by each crime is altered. Increasing $\dot{z}$ causes the equilibrium value of η to fall (despite $\frac{\partial \eta}{\partial \dot{z}} > 0$ for the optimal allocation in the absence of competition). If criminals of one crime gain a greater amount of utility if successful relative to the other, then the resulting value of η tends towards the crime offering the greater utility for success (so increasing the value of $\dot{u}$ relative to $\ddot{u}$ results in an increase in the value of η). The final variable, the sanction imposed if caught, demonstrates a benign federal government is able to prevent any distortion from occurring; a less benign federal government can ensure police resources are allocated in a manner of its liking. If $\dot{v}$ is lowered relative to $\ddot{v}$, so the sanction becomes harsher, the value of η falls. Thus decreasing $\dot{v}$ in units of 1 from $\dot{v} = -1$ gives equilibrium values of η of 0.968, 0.653, 0.500, 0.401 and 0.329 so the federal government can influence how funds are allocated when determining sanctions. Therefore the effect of competition between jurisdictions need not only be restricted to the tax rate; the allocation of funds between crimes can also be affected.

Proposition 9 *Competition between jurisdictions can also affect how the police allocate resources between crimes.*

3.5 Objective functions

So far it has been assumed that the jurisdictions' governments aim to maximise the non-locational utility of their non-criminal residents. This is not the only objective the government could hold; in the UK police authorities are, within certain limits, able to determine taxes to fund the local police force and could choose instead to focus on policing objectives, for example maximising the arrest rate. Only a third of police authority members are elected politicians serving in local government and therefore authorities might not feel duty-bound to follow utility maximising objectives. This section presents four different objectives local government could hold and suggests another benefit of tax competition is the ability to limit

the amount of tax the jurisdictional government is able to levy.

The first variation is for the government to minimise the damage resulting from crime, thus the government will set a tax that minimises $\frac{q(1-p)x_1 z}{x_2}$ given the migration response of both victims and criminals. The resulting pure strategy Nash equilibrium tax rate solves

$$1 - z(1-p)\left[\frac{\partial q}{\partial t}\right] + qz\left[\frac{\partial p}{\partial t}\right] + 2d_2\left[\frac{\partial x_2}{\partial t}\right] = 0. \tag{3.28}$$

This follows the same functional form as when utility was maximised, though the direction of the constant has changed as the level of tax is now absent. Returning to the numerical example, though with $v = -6$ (rather than $v = -3$ so the optimal tax in the base model is undistorted), the equilibrium tax when aiming to minimise the damage caused by crime is $t = 0.192$. Unsurprisingly this is higher than when the tax rate itself is included in the objective function ($t = 0.167$), however it is lower than the tax that would be levied in the absence of tax competition, $t = 0.667$. Although the equilibrium tax rate is higher than optimal for its voters, as the government excludes the disutility from the loss of income it generates, their ability to move to another jurisdiction, if it offers a lower tax rate, restricts the ability of either jurisdiction to increase the tax. Thus the local government is unable to levy the tax that minimises their objective function in the absence of interjurisdiction externalities; the tax is competed downwards. Therefore the presence of tax competition limits the extent to which the local government is able to tax to meet their objectives when their preferences diverge from their electorate's.

An alternative aim for a police authority could be to maximise the arrest rate (or analogously to maximise the prevention of crime). The arrest rate is the proportion of crimes so the objective function becomes $\max p$; the arrest rate is the number of arrests made divided by the number of crimes or $\frac{qpx}{qpx+q(1-p)x} = p$. The pure strategy Nash equilibrium is the tax rate that solves

$$2t\left(\left[\frac{\partial x_1}{\partial t}\right] - \left[\frac{\partial x_2}{\partial t}\right]\right) = 1. \tag{3.29}$$

The optimal tax in the absence of tax competition is $t = 0.667$; the linearity of the probability of arrest function means the government will continue to tax until either $p(t) = 1$ or $t = 1$.

Using the same values as before the equilibrium tax rate is $t = 0.148$. Again the ability of taxpayers to move jurisdictions limits the tax a jurisdiction's government can levy to fulfil its objective.

Another policing related objective the government could hold is to minimise the crime rate, which can be defined as the number of attempted crimes. Therefore the domestic government chooses to min $\frac{qx_1}{x_2}$ and the pure strategy Nash equilibrium is the tax rate that solves

$$\left[\frac{\partial q}{\partial t}\right] + 2\left(\left[\frac{\partial x_2}{\partial t}\right] - \left[\frac{\partial x_1}{\partial t}\right]\right)\left(\left[\frac{\partial q}{\partial t}\right] t - q\right) = 0. \tag{3.30}$$

Again the optimal tax in the absence of tax competition is $t = 0.667$ but this is now due to the linearity of q. Likewise the equilibrium tax rate, $t = 0.175$, is lower than the one a jurisdiction's government would prefer.

The final objective function a jurisdiction's government could have is to minimise the number of criminals residing in the jurisdiction. The pure strategy Nash equilibrium, when the government has the aim of min qx_1, is the tax rate that solves

$$q\left[\frac{\partial x_1}{\partial t}\right] + \left[\frac{\partial q}{\partial t}\right]\left[1 + 2t\left(\left[\frac{\partial x_2}{\partial t}\right] - \left[\frac{\partial x_1}{\partial t}\right]\right)\right] = 0. \tag{3.31}$$

The story here is the same as before. The equilibrium tax rate ($= 0\ 144$) is less than the optimal tax rate ($= 0\ 667$) as the movement of taxpayers prevents the leaders of a jurisdiction from raising taxes too far to meet their objective.

This section has so far assumed $= 1\ \ {}^{3}_{2}\ {}^{2}_{1}$, which limits the tax to $\ \ {}^{2}_{3}$ at the equilibrium, in order to be consistent with previous sections. However the results of this section do not change if the distribution of s alters so $= {}^{4}_{5}\ 1\ \ {}^{2}_{1}$ whilst remains unaltered. When the objective function is to maximise utility the equilibrium tax levied is 0.272 despite the optimal tax being 1. If the jurisdiction aims to maximise the arrest rate then the equilibrium tax becomes 0.25, which is lower than the optimal tax (for the jurisdiction's government) of 1. Likewise when the objective function is to minimise the crime rate the resulting equilibrium tax is either 0.282 or 0.560, both of which are lower than the optimal tax of 1. Finally if the aim of the jurisdiction is to minimise the harm resulting from crime then the equilibrium

tax rate can be either 0.298, 0.389 or 1. Given the global optimal tax is 1 it is theoretically possible for tax competition to result in both jurisdictions setting their preferred tax rate.

The question arises as to which tax rate a jurisdiction chooses when there are multiple pure strategy Nash equilibria. Assume there are two pure strategy Nash equilibria, $\widehat{t}$ and $\widehat{t^*}$ with $\widehat{t} < \widehat{t^*}$. Further assume that the domestic jurisdiction levies $\widehat{t}$ whilst the foreign jurisdiction chooses $\widehat{t^*}$. As the jurisdictions levy different tax rates the proportion of taxpayers and potential criminals will also alter. The new allocation of individuals between jurisdictions will be the $x_1 = x_1(\widehat{t}, \widehat{t^*})$ and $x_2 = x_2(\widehat{t}, \widehat{t^*})$ that solve (3.1) and (3.3), given $t = \widehat{t}$ and $t^* = \widehat{t^*}$. Both groups will experience movement towards the jurisdiction that offers the higher utility. For taxpayers this means they will move to the domestic jurisdiction if the increase in post tax income is greater than the change in security offered whilst potential criminals will move towards the jurisdiction offering the greater return from crime. Firstly assume the possibility of a corner solution. Assume the initial response of taxpayers to the different tax rates is to migrate towards the domestic jurisdiction, then if

$$d_2 \leq \widehat{t^*} - \widehat{t} + [1 - q_1(1 - p_1)x_1]\, z \tag{3.32}$$

for all $x_1 \in [0, 1]$ (where $p_1 = p\left(\frac{\widehat{t}}{x_1}\right)$, $q_1 = q\left(\frac{\widehat{t}}{x_1}\right)$, $p_2 = p\left(\frac{\widehat{t^*}}{1-x_1}\right)$ and $q_2 = q\left(\frac{\widehat{t^*}}{1-x_1}\right)$) all the taxpayers will reside in the domestic jurisdiction. The attachment to home measure for taxpayers has to be sufficiently small in order for the last individual with locational preference 1 to move jurisdiction. If (3.32) does not hold then some taxpayers will continue to reside in the foreign jurisdiction even though they could be a victim of crime with probability one - their preference for the foreign jurisdiction dominates the other components of utility. The movement of criminals is not, unfortunately, as simple. If (3.32) holds with either $q_1 = q\left(2\widehat{t}\right) = 0$ or $p_1 = p(2\widehat{t}) = 1$ then all the taxpayers will reside in the domestic jurisdiction free from crime, though still paying tax of $\widehat{t}$, whilst the potential criminals reside in their preferred jurisdiction (as they are unable to undertake crime in either jurisdiction they will settle according to their locational preference). Thus the domestic jurisdiction will house all the taxpayers and half the potential criminals (who are unable to commit crime either because

they will automatically be arrested or because the expected value from committing crime is not sufficiently high) whilst the foreign jurisdiction will house the remaining criminals unable to commit crime due to the lack of victims.[8] If neither $q_1 = q\left(2\widehat{t}\right) = 0$ nor $p_1 = p(2\widehat{t}) = 1$ but $x_2 = 1$, potential criminals with $x_i \leq \frac{1}{2}$ will reside in the domestic jurisdiction. They will be joined by those with a locational preference $x_i > \frac{1}{2}$ if

$$(1-p)u + pv - \varepsilon_i > d_1(2x_i - 1) \tag{3.33}$$

given all the taxpayers reside in the domestic jurisdiction. A potential criminal will only move jurisdiction if the return from crime over and above their requirement is greater than the loss of utility resulting from residing in the jurisdiction.

If (3.32) does not hold for the value of x_1 which results after potential criminals have made their residency decision then not all the taxpayers will reside in the domestic jurisdiction; the increase in the number of potential criminals decreases the effectiveness of the police, lowers the level of security provided which in turn causes those with the strongest preference for the foreign jurisdiction to return home. Accordingly there can be an interior solution for x_2 and, consequently, also for x_1. Unless $V(x_1, x_2, \widehat{t}) = V(x_1, x_2, \widehat{t^*})$ one jurisdiction will be closer to fulfilling their objective function than the other (where $V(\cdot)$ represents the value of the objective function given the location decisions of both groups and the tax rates levied by the jurisdictions) so one pure strategy Nash equilibrium tax rate will dominate the others allowing the jurisdictions to coordinate and levy the same tax.[9] If $V(x_1, x_2, \widehat{t}) > V(x_1, x_2, \widehat{t^*})$ then both jurisdictions will charge $\widehat{t}$ if aiming to maximise V whilst if $V(x_1, x_2, \widehat{t}) < V(x_1, x_2, \widehat{t^*})$ then both jurisdictions will levy $\widehat{t^*}$. Thus one of the pure strategy Nash equilibria tax rates will dominate the others allowing the jurisdictions to coordinate their tax rates and levy the same tax. It is not necessarily the lower tax rate that will dominate. If $V(x_1, x_2, \widehat{t}) = V(x_1, x_2, \widehat{t^*})$ then it is possible for both jurisdictions to levy different tax rates achieve the same objective and therefore asymmetric allocations could result. Returning to the numerical example, (3.32)

[8] This argument assumes there is no victimless crime and only taxpayers can be the victims of crime.

[9] Although technically if no taxpayers reside in a jurisdiction then there can be no crime it is assumed this scenario is not seen as desirable by a jurisdiction's government.

holds for all values of $d_2 < 1.34$ (setting $x_1 = 1$). Given $d_2 = 1$ all the taxpayers will move to the domestic jurisdiction, though crime will not be eliminated, so $t = 0.298$ dominates $t = 1$ preventing the jurisdictions levying their optimal tax.

In reality a police authority will not have one sole objective, rather their objective function will be a composite of different aims. However the presence of tax competition, allowing different jurisdictions to levy different tax rates, can limit the extent to which a police authority is able to tax and meet its objectives. Even if the tax rate is not explicitly included in the objective function the migration response of taxpayers away from higher than optimal taxes can limit the tax that is levied.

3.6 Misspecification and the fear of crime

Another variant to the model is to introduce misspecified probability functions and fear of crime into the model. If the potential victims of crime misspecify the probability functions, so their belief of the police production function is different to the actual, the functional form of the equilibrium tax remains unaltered. As the order of the game is the jurisdictions set their tax rates first, people settle in one of the jurisdictions and then crime is committed, potential victims will settle according to their expectation of what police expenditure can achieve and therefore the misspecified probability of being a victim of crime will be used. Thus the equilibrium tax will still be given by (3.5), though p and q are replaced by their modified versions in both (3.4) and (3.5) but are unaltered in (3.2). Likewise potential criminals can also misspecify the police production function. For the same reason as before the structure of the equilibrium tax remains unaltered, however both p and q in (3.2) are replaced by their modified forms. If potential victims are unaware of the potential criminals' misspecifiaction then both (3.4) and (3.5) remain unaltered so only the equilibrium migration response of potential criminals changes. If the potential victims are aware of the misspecification then the modified form of q is used in both (3.4) and (3.5). Thus misspecification has no effect on the structure of the equilibrium tax.

Following on from misspecified probability functions is the introduction of fear of crime into the utility functions of potential victims. The simplest way of introducing the fear of crime is to include it linearly, so the utility of a potential victim in the domestic jurisdiction becomes $1-t-\frac{q(1-p)x_1}{x_2}z-\frac{\widetilde{q}(1-\widetilde{p})x_1}{x_1}\widetilde{z}-d_2x_2$ where $\widetilde{\cdot}$ represents the function or value relating to fear.[10] If potential victims of crime, along with criminals, perfectly understand the effect of police expenditure on the probability of arrest and probability of participation (so $p=\widetilde{p}$ and $q=\widetilde{q}$) then the effect of fear of crime is to replace z by $z+\widetilde{z}$ in (3.2), (3.4) and (3.5); as there is perfect knowledge the fear of crime just increases the harm caused by crime. It is possible for the probability functions to be misspecified, as in the previous paragraph, but with p and q taking on the misspecified form.

However it is also possible for p and q and $\widetilde{p}$ and $\widetilde{q}$ to take different functional forms. Whilst ex post p and q will always take on the correct values, ex ante it is possible for them to be correct and $\widetilde{p}$ and $\widetilde{q}$ be wrong. The inconsistency between the two can be explained by there being perfect knowledge regarding the probability of being a victim of crime whilst the fear of crime is more subjective. The British Crime Survey (Home Office, 2006) reports the disparity between people's knowledge of crime in their local area and their knowledge of crime in general; people are better informed about local crime. Alternatively the fear of crime term can represent the security that is felt, which can be independent of the probability of being a victim of crime. Therefore the equilibrium migration response of potential victims to a change in the domestic tax rate is given by

$$\left[\frac{\partial x_2}{\partial t}\right]=\frac{-1+(4t\left[\frac{\partial x_1}{\partial t}\right]-1)A-B\left[\frac{\partial x_1}{\partial t}\right]}{2d_2+4tA-B} \tag{3.34}$$

where $A=[(1-p)\left[\frac{\partial q}{\partial t}\right]-q\left[\frac{\partial p}{\partial t}\right]]z+[(1-\widetilde{p})\left[\frac{\partial \widetilde{q}}{\partial t}\right]-\widetilde{q}\left[\frac{\partial \widetilde{p}}{\partial t}\right]]\widetilde{z}$ and $B=4q(1-p)z+4\widetilde{q}(1-\widetilde{p})\widetilde{z}$. This follows the same form as before, with the fear of crime entering in the same way as the actual crime measure. The functional form of the equilibrium migration response of potential criminals is unaltered, though the value changes as $\left[\frac{\partial x_2}{\partial t}\right]$ has changed.[11] Therefore the pure

[10] A more complex way of introducing fear of crime is to make the expression decreasing and concave in the probability of being a victim of crime.

[11] This assumes potential criminals gain no utility from the fear of crime they can engender.

strategy Nash equilibrium tax is the tax rate that solves

$$-1 - z(1-p)\left[\frac{\partial q}{\partial t}\right] + qz\left[\frac{\partial p}{\partial t}\right] - \widetilde{z}(1-\widetilde{p})\left[\frac{\partial \widetilde{q}}{\partial t}\right] + \widetilde{q}\widetilde{z}\left[\frac{\partial \widetilde{p}}{\partial t}\right] + 2d_2\left[\frac{\partial x_2}{\partial t}\right] = 0. \qquad (3.35)$$

As usual tax competition distorts the optimal tax by introducing the equilibrium migration response of the taxpayers into the first order condition. In the numerical example the fear of crime measures respond in the same way as the actual crime, for example an increase in $\widetilde{z}$ increases the equilibrium tax whilst an increase in $\widetilde{c}$ causes it to fall. As long as the jurisdictions' governments know how the probability functions are misspecified or how its residents fear crime, then the resulting equilibrium taxes will include them in the usual manner.

3.7 All pay tax

A key assumption so far has been non-taxpayers commit crime against taxpayers. This is a restrictive assumption that has run throughout this chapter and therefore is the last to be realxed. Assume the ratio of potential criminals to potential victims is θ, $\theta = \frac{n_1}{n_2}$. This means the probability of arrest in the domestic jurisdiction becomes $p = p\left(\frac{\theta x_1 t + x_2 t}{x_1}\right) = p\left(\theta t + \frac{x_2 t}{x_1}\right)$ whilst the probability any potential criminal attempts to commit a crime is $q = q\left(\theta t + \frac{x_2 t}{x_1}\right)$. In order for them to pay tax it is assumed they also receive a dividend income of one, thus this section models crime in a community of similar people. The marginal potential criminal indifferent between the two jurisdictions is located at x_1, where

$$1 - t + q[(1-p)u + pv] - d_1 x_1 = 1 - t^* + q^*[(1-p^*)u + p^* v] - d_1(1 - x_1) \qquad (3.36)$$

with the modified forms of the probabilities used: p, p^*, q and q^*. The equilibrium migration response of a potential criminal at the equilibrium is

$$\left[\frac{\partial x_1}{\partial t}\right] = \frac{-1 + (4t\left[\frac{\partial x_2}{\partial t}\right] + 1 + \theta)\left\{[(1-p)u + pv]\left[\frac{\partial q}{\partial t}\right] - q(u-v)\left[\frac{\partial p}{\partial t}\right]\right\}}{2d_1 + 4t\left\{[(1-p)u + pv]\left[\frac{\partial q}{\partial t}\right] - q(u-v)\left[\frac{\partial p}{\partial t}\right]\right\}}. \qquad (3.37)$$

This expression is similar to (3.2), however the addition of -1 in the numerator stems from the direct effect the tax has on their income whilst the addition of θ signifies the effect of the extra tax yield from the potential criminals now paying tax. The marginal potential victim

indifferent between the two jurisdictions is still given by (3.3), though with the modified probability functions, and thus the equilibrium migration response of a potential victim to a change in the domestic tax rate at the equilibrium is

$$\left[\frac{\partial x_2}{\partial t}\right] = \frac{-1 + (4t\left[\frac{\partial x_1}{\partial t}\right] - 1 - \theta)\left\{(1-p)\left[\frac{\partial q}{\partial t}\right] - q\left[\frac{\partial p}{\partial t}\right]\right\} z - 4q(1-p)z\left[\frac{\partial x_1}{\partial t}\right]}{2d_2 + 4tz\left\{(1-p)\left[\frac{\partial q}{\partial t}\right] - q\left[\frac{\partial p}{\partial t}\right]\right\} - 4q(1-p)z}. \tag{3.38}$$

The effect potential criminals paying tax has on the equilibrium migration response of potential victims is twofold. The first direct effect is to increase the value of the numerator as potential criminals paying tax adds to the potential victims' security. The second effect occurs indirectly through the change in the equilibrium migration response of the potential criminals.

Assuming $n_2 > n_1$ then the aim of the jurisdiction is to maximise the non-locational utility of its residents who are the potential victims, $\max 1 - t - \frac{q(1-p)x_1}{x_2}z$, which means the pure strategy Nash equilibrium tax rate is the tax that solves

$$-1 - (1+\theta)\left[z(1-p)\left[\frac{\partial q}{\partial t}\right] - qz\left[\frac{\partial p}{\partial t}\right]\right] + 2d_2\left[\frac{\partial x_2}{\partial t}\right] = 0. \tag{3.39}$$

This follows the usual structure with tax competition introducing a distortion depending on the equilibrium migration response of potential victims. To determine the effect an increase in the proportion of potential criminals (an increase in θ) the equilibrium migration response of the potential victims when the equilibrium tax is levied can be rewritten as $\frac{\partial x_2}{\partial t} = \frac{\varphi\chi(1+\theta)-\chi}{2d_1(4d_2+\chi)+16t\varphi d_2}$, where $\varphi = [(1-p)u + pv]\left[\frac{\partial q}{\partial t}\right] - q(u-v)\left[\frac{\partial p}{\partial t}\right]$ and $\chi = 4tz\left\{(1-p)\left[\frac{\partial q}{\partial t}\right] - q\left[\frac{\partial p}{\partial t}\right]\right\} - 4q(1-p)z < 0$. Assume that $(1+\theta)\frac{\partial p(\theta,t)}{\partial t} = \frac{\partial p(t)}{\partial t}$ and $(1+\theta)\frac{\partial q(\theta,t)}{\partial t} = \frac{\partial q(t)}{\partial t}$; this is analogous to stating that an increase in θ has no effect on the total population, rather an increase in θ means the proportion of potential criminals increases though the taxbase remains the same size. With this assumption both φ and χ are independent of θ and therefore $\frac{\partial x_2'}{\partial \theta} = \frac{\varphi\chi}{2d_1(4d_2+\chi)+16t\varphi d_2}$. If $\varphi < 0$ then the equilibrium tax is increasing in θ when $2d_1(4d_2+\chi) + 16t\varphi d_2 > 0$. If $\varphi > 0$ then the equilibrium tax is increasing in θ if $2d_1(4d_2+\chi) + 16t\varphi d_2 < 0$. Under these conditions the equilibrium migration response of the potential victims increases in θ which in turn, from (3.39), requires the equilibrium tax to rise.

Table 3.5: Equilibrium tax rates: criminals pay tax

		$\frac{100\theta}{(1+\theta)}$ 1	5	10	15	20	25	30	35	40	45	49
z	1	0.273	0.275	0.279	0.284	0.289	0.295	0.302	0.310	0.320	0.330	0.340
	2	0.274	0.282	0.292	0.302	0.313	0.324	0.336	0.349	0.362	0.376	0.388
	3	0.275	0.288	0.302	0.317	0.331	0.345	0.360	0.375	0.391	0.407	0.421
	4	0.277	0.293	0.312	0.329	0.346	0.362	0.379	0.396	0.414	0.453	0.450
	5	0.278	0.298	0.320	0.340	0.358	0.377	0.395	0.414	0.434	0.460	0.520
	6	0.279	0.303	0.327	0.349	0.370	0.390	0.410	0.431	0.458	0.538	0.611
	7	0.280	0.307	0.334	0.358	0.380	0.402	0.424	0.450	0.513	0.608	0.658
	8	0.281	0.311	0.341	0.366	0.389	0.413	0.438	0.480	0.580	0.649	0.667
	9	0.283	0.315	0.347	0.373	0.398	0.423	0.454	0.537	0.622	0.667	0.667
	10	0.284	0.319	0.352	0.380	0.407	0.434	0.482	0.584	0.652	0.667	0.667

In the numerical example the coefficients $b = \frac{3}{2}$ and $d = \frac{1}{2}$ are replaced by $b = \frac{3}{2(1+\theta)}$ and $d = \frac{1}{2(1+\theta)}$ (so a change in θ has no effect on the size of the taxbase). Similarly z is replaced by $z\theta$; z implicitly includes the ratio of potential criminals to potential victims and therefore any change in θ has to be included in z for the harm to remain constant (with $z = 1$). Table 3.5 gives the equilibrium tax rates when both θ and z vary. The columns represent potential criminals as a proportion of the total population. As the proportion increases so does the tax rate. Further, the tax rate is convex in the proportion of potential criminals. Thus as potential criminals become more prevalent, increasing the probability of becoming a victim, the tax increases to partially compensate the decrease in security it causes. The rows represent the harm a crime inflicts (independent of θ). As before, for the single crime model, the equilibrium tax increases in the harm a crime causes.

3.8 Conclusion

This chapter has presented a more generalised model of crime and investigated the properties the pure strategy Nash equilibrium tax can have and introduced some variations to the model to demonstrate the effect tax competition can have on policing. In the generalised model of crime, where the harm caused to the victim and the payoff or sanction for the criminal, depending on whether they are caught, can be expressed in fixed monetary terms, the effect of tax competition is to introduce the same distortion to the first-order Nash condition as in

the previous chapter. The presence of the equilibrium migration response of potential victims causes the tax rate to be higher than optimal if the migration response of potential victims is positive at the equilibrium tax rate; if it is negative at the equilibrium tax rate then the equilibrium tax rate will be below the optimal tax rate. Thus changing the type of crime has no effect on the structure of the equilibrium tax.

In models of tax competition where the tax receipts are used to provide a public good there is typically a race for the bottom as the capital becomes more mobile. In this model, where the tax receipts are used to provide security, it is possible for the tax to diverge from the optimum as capital becomes more mobile. Likewise it is possible for the comparative statics of the equilibrium tax to be different to the comparative statics of the optimal tax, for example in relation to the production functions of the police (either through the detection function, p, or the prevention function, q). However the potential distortion in taxation can, in certain circumstances, be prevented by the federal government if it chooses the optimal punishment. However this optimal punishment is only optimal in relation to tax competition and has no relation to the harm caused by the crime. The practicalities of using fiscal considerations in determining a sanction could present difficulties for a policy maker, but the policy maker needs to be aware that any sanction will influence the tax levied at the local level for policing.

Despite the potential distortion to the resulting tax that tax competition can cause, it can bring some benefits. For example a crime which only affects a minority of the taxpaying population can have more resources allocated to it than would occur in the absence of tax competition. Further a tax can be levied if there is tax competition when none would be levied if tax competition was absent. Similarly the movement of the taxbase can limit the extent to which a police authority is able to tax to meet any objective the federal government sets, bringing the equilibrium tax closer to the non-locational utility maximising tax rate. However this benefit only occurs due to the existence of police authorities; a federal government would be seeking re-election and thus be focused on maximising utility. All the members of a police authority are appointed (with a third being appointed from local politicians) meaning there are

limited re-election concerns and therefore they are able to focus solely on policing objectives.

To conclude, both the previous chapter and this demonstrate allowing local governments to determine taxes to provide police services can result in suboptimal taxes being levied. Although it is possible to mitigate the distortion through the sanction imposed if caught or, potentially, through the choice of the police objective function, the policy implication of these papers is that it is better for policing related taxes to be determined at the federal level. Further when there are two crimes competition between the jurisdictions can lead to suboptimal allocations between the crimes even when the tax rate is determined centrally. Therefore the federal government ought also to determine how the resources are to be allocated between crimes. Following this argument is not necessarily the same as arguing for a national, centralised police force. Although police authorities should be stripped of their precepting status and the ability to influence the allocation of resources, they still provide other beneficial functions, for example local oversight of the police force. Therefore these other functions could provide sufficient grounds for retaining police authorities but without their tax and allocation powers. When the plans to merge the smaller police forces are reintroduced, the source of funding for the larger police forces should also be addressed.

Part II

The Ministry of Defence's naval procurement policy

Chapter 4

The Ministry of Defence's naval procurement policy since 1985

> ... we have moved on from the days where we gave the contract to the lowest compliant contractor. It actually makes it clear there are circumstances where you could take a short-term view and lose out in the long-term, both as a customer and in broader senses.
>
> Chief of Defence Procurement, Q117, DC, 2003.

At the start of the 1980s competition was an anathema to the defence industries in the United Kingdom. As de Fraja and Hartley (1996) state the Ministry of Defence (MoD) awarded cost-plus or cost-based contracts without recourse to competition. This, however, changed after the Levene reforms which aimed to introduce competitive procurement to the MoD. Unfortunately when it came to warship procurement the MoD was still unable to have a fully competitive regime as all the major shipyards were in British Shipbuilders, the nationalised shipbuilding firm. As a monopoly British Shipbuilders allowed their yards only to compete in costs, not on the profit rate. Consequently they were able to maintain higher profits on warship contracts than the target profit allowed by government (para 5.2, NAO, 1985). This came to an end with the privatisation of British Shipbuilders; the warship yards were amongst the first to be privatised given their profitability. Johnman and Murphy (2002) suggest that some yards were misclassified as warship yards to ensure there would be keen competition for MoD contracts. Being classified as a warship yard meant the yard was unable to receive state aid for commercial shipbuilding so it would be unable to bid competitively for commercial work meaning the yard's future depended on winning MoD contracts (by submitting lower prices.) The result of privatisation was that the MoD was finally able to obtain competition for surface warship contracts.

Due to the Darwinian nature of competition winning a competition ensured survival of a shipyard for a few more months whilst losing one could mean calling the receivers in. The MoD saw each contract individually rather than part of a series. Accordingly even when the competition became fierce and yards closed, the MoD continued to use competition to allocate contracts though allegations of contracts being placed with yards for political reasons remained. Whilst competition ensures the efficient allocation of resources it requires proper management to ensure there is true competition between firms and that long term efficiency is not jeopardised through the creation of a monopoly. As the MoD failed to manage the competition the state of the industrial base was a by-product of competition rather than any particular shape desired and molded by the MoD. If a monopoly were to be the result then the MoD believed it would be able to introduce competition either by using the remaining commercial shipyards or the dockyards (NAO, 1993). Competition continued unabated through the 1990s. By the turn of the century most of the major shipyards had survived (although some of them had lost the ability to undertake warship production). The turn of the century was also to coincide with a programme to renew the surface fleet. That there would be competition for each project as and when they came to be ordered was by accident rather than any MoD design.

With a large number of orders pending the MoD started to take a longer-term view of procurement and the effect that a procurement decision made today will affect the procurement decisions that are able to be made tomorrow – in effect the trade-off between short and long term efficiency. Whilst it was forced into this position on the Type 45 contract (when one firm made an unsolicited bid to produce the whole contract in order to gain a monopoly in warship building), it was written more generally in the Defence Industrial Policy (MoD, 2002). This stated that if the result of a procurement decision affects the industrial base then this has to be considered when awarding the contract. This applied beyond shipbuilding to all areas of defence procurement and meant that a firm can still win a contract even if it does not submit the lowest bid by highlighting the number of jobs that would be lost and

the loss of future competition. Intuitively the result of the policy would be that contracts are spread more evenly amongst the remaining yards to ensure limited competition remains. However if a yard knows that the policy effectively states the government will not allow a yard to close then it allows the firms to increase their prices and make profits that would not be available to them under normal competition. Whether or not this conjecture is valid does not, (un)fortunately, remain to be seen as problems on the carrier contract have left the MoD desiring the industry to restructure itself so that it combines and works in partnership with one another (and in partnership with the MoD.) This would leave the MoD to deal with a single entity whose members would ensure that each firm survives. The practical effect, if the scheme is successful, is to return the MoD to deal with a monopoly again.

The aim of this chapter is to argue that the MoD does need to consider the effects its current warship procurement decisions have on future decisions. It expands the preceding discussion by detailing how the MoD has viewed future competition for its naval procurement programme and the consequence of these views. The argument is the MoD has placed insufficient emphasis on future competition since the 1980s but has not had to pay any increased costs as a result due to the manner in which British Shipbuilders was privatised and, latterly, to the end of the Cold War and the resulting reduction in the naval procurement programme. However given the forward naval procurement programme and the shipyards that have survived it is likely the MoD will have to pay more in the future. Therefore this chapter is also an introduction to the next chapter which argues that the government can maintain competition and limit the rents firms are able to earn by taking a more proactive role in the market rather than relying on conventional competition.

4.1 Up to 1990

After the Second World War the Warship Group (those involved in the construction of naval ships in the UK) consisted of twelve shipyards. This situation remained, with all the shipyards competing against one another for government contracts, until the Geddes commission of

1965/66 (Geddes, 1966). This was the first official post-war inquiry into the shipbuilding industry, both commercial and naval. The report's main recommendation was that shipyards ought to group together to create fewer new firms, each with the same configuration and roughly the same size so as to be able to compete against one another. When focusing on the the role of naval procurement it suggested contracts were distributed too thinly with twelve yards present. Consequently the yards undertook a mixture of naval and commercial work ensuring their inability to be efficient in either market. Furthermore the yards had become over-reliant on naval orders and other complicated ships which inhibited them building the other types of ships then in demand by commercial shipowners. The solution proposed was to concentrate production of surface warships in just three specialist warship yards whilst continuing production of nuclear submarines at the two yards then producing them (Vickers and, to a lesser extent, Cammell Laird). Geddes argued the reduction in the number of firms would not lead to a loss of competition in naval procurement. The main factor that would limit the yards' ability to undertake work was insufficient fitting out labour but by specialising in naval work efficiency would increase. Additionally all the remaining firms should be able to bid for contracts if labour could be transferred within the group or by the use of casuals at peak production times. Furthermore the MoD should be able to use the Royal Dockyards as a comparison by which to compare costs from the remaining firms. Geddes viewed three firms as being optimal; although full competition could be maintained with four, five or six firms this would result in the yards having to mix naval and commercial work which would continue to ensure the yards were inefficient in both markets.

By 1972 Hogwood (1979) reports there were three specialist builders in the naval sector (Vickers, Yarrow and Vosper Thornycroft) and three non-specialists (Cammell Laird, Swan Hunter and Scott Lithgow). The Booz-Allen report into the British shipbuilding industry reinforced the Geddes report by recommending the policy of a small number of dedicated warship yards, as part of larger groupings, be continued. Although these groupings of yards were able to compete for and win naval contracts, the downturn in the commercial market

in the 1970s left the industry facing an uncertain future yet again. The response of the government was to nationalise the major yards in England and Scotland in summer 1977 to form British Shipbuilders. The consequence of the MoD having to purchase its warships from the monopoly of British Shipuilders was demonstrated by a National Audit Office (NAO) report which stated that warship competitions were limited to the cost of production as British Shipbuilders ordered the shipyards to maintain a common high rate of profit at around 11%, 2% higher than the target profit allowed for by the profit formula for non-competitive government contracts (para 5.2, NAO, 1985). Although there was limited cost competition for surface ships the government was reliant on a domestic monopoly for its purchase of nuclear submarines. Vickers Shipbuilding and Engineering Ltd was, by this time, the sole producer and managed to exploit its position to obtain favourable contract terms. The average variation in estimates for build hours between Vickers and the MoD, according to a NAO sample, was 21%, with a 43% difference in the worst case. Furthermore the MoD's estimates were "more accurate but negotiations generally led to a considerable move towards the contractor's estimates" (para 5.6, NAO, 1985). Only for the contract for a Type 42 where there was already knowledge from other shipyards as to the number of man hours necessary was the actual close to the contractual. The construction of nuclear submarines clearly demonstrated the problems (both in terms of price and power) that the MoD would face in surface shipbuilding if ever a proper monopoly occurred there (as British Shipbuilders at least allowed cost competition).

In 1979 a new government was elected which aimed to introduce a new way of business for defence procurement. Despite the MoD purchasing a third of the output of British yards in 1981 the lack of competition was lamented as competition was viewed to encourage lower prices, greater efficiencies, innovation and higher quality and whilst the government were not prepared to pay an undue premium for maintaining competition it would do so if it could (p46, MoD, 1981). Lower prices were not the only aim of privatisation; the government also wished to lower the risk attached to projects. A warship can roughly be separated into two parts: a hull and the systems. Whilst the shipbuilders built the hull, a platform for the systems, the

system houses designed the systems for the ship and as separate firms were contracted for each task the risks of integrating them, in financial, time and quality terms, fell on the MoD. The MoD were hoping that there would be vertical integration after privatisation with systems houses purchasing shipyards so future procurements could be offered to prime contractors with the risk passed onto them (Q2657, PAC, 1985). The government had been elected with a manifesto commitment to privatise British Shipbuilders and the Minister of State at the DTI in 1983 maintained that this "offered the best way to secure jobs and achieve maximum efficiency" (Hansard, 1358, 46). The first yard to be privatised was Scott Lithgow, previously a warship yard but instead having an expensive involvement in the offshore market at that time, in order to help stem British Shipbuilders' financial loss. Scott Lithgow alone lost around £75m out of British Shipbuilders total loss of £160.9m in 1983/84 (Hansard, 998, 64). The warship yards were next to be privatised as they were attractive, having made a profit of £43.8m in the same year; during the early 1980s the warship yards consistently made a profit of £40m to £50m a year. Unfortunately these profits, essentially a transfer from the MoD's to the DTI's budget, were not due to greater efficiency. According to the Chairman and Chief Executive of British Shipbuilders the warship yards were less efficient than the commercial yards. The reasons given were warship builders were less exposed to commercial realities and consequently did not acknowledge the need to reform combined with them possessing less sophisticated manufacturing processes due to less knowledge being transferred amongst the warship yards (Q2660, PAC, 1985). The announcement of the privatisation of the warship yards was made on the 25th July 1985. There was, however, some controversy as to which were warship yards. Those that qualified for privatisation by the 31st March 1986 as warship yards were: Vickers, Yarrow, Vosper Thornycroft, Hall Russell, Brooke Marine, Cammell Laird and Swan Hunter. Being classified as a warship yard, for the smaller and mixed yards[1], was more a hinderance than a help. Although it meant they were able to compete for profitable naval contracts it forbid them for state funding when competing for orders in the civilian market

[1] A mixed yard is one that undertakes both merchant and warship building, for example Cammell Laird and Swan Hunter.

Table 4.1: The rate of profit and employment in warship yards in the 1980s

	Profit rate			Employment		
	1979/80	1984/85	Late 1980s	1979/80	1984/85	Late 1980s
Brooke Marine	14.3	(7.7)		785	635	
Cammell Laird	(21.0)	(19.5)		3617	2037	
Hall Russell	3.6	0.4		832	782	
Swan Hunter	(17.5)	10.8	4.0	9787	7189	2750
Vosper Thornycroft	27.9	12.6	12.5	5210	4360	1900
VSEL	7.9	7.3	3.8	13513	12448	14900
Yarrow Shipbuilders	12.8	8.3	8.7	5359	5427	4000
All warship yards	3.2	7.0	5.1	39103	32878	23550

Employment data taken from and profit rate constructed from Annex B, TIC, 1989.

under European rules (intervention funding of 9% was only available to non-warship yards). The consequence was that they would be unlikely to win merchant ships without the state aid and therefore were reliant on winning MoD contracts (forcing them to submit keen prices). Johnman and Murphy suggest the classification was given to these seven yards "in order to increase competition in the [warship] sector with the aim of driving down prices" (p217, 2002).

Table 4.1 shows the profit rate and employment levels of the yards just after British Shipbuilders was established (1979/80), just prior to privatisation (1984/85) and after privatisation (the late 1980s). The figures suggest the profit rate fell over the decade (suggesting increased competition) as did employment figures (from fewer orders and, possibly, an increase in efficiency). Privatisation meant it was for the market to determine the appropriate price of a yard, taking future prospects for the industry into account. It should be noted that there are difficulties in determining the exact price of sale for each yard as each contract placed a liability on the government for future redundancies but also offered profit sharing on future orders.[2] However using the ratio of sale price to profit as a measure of confidence in the future VSEL has the highest measure (4.20) followed by Yarrows (3.99), Vosper Thornycroft (1.55), Swan Hunter (0.37), Brooke Marine (-0.05) and finally Hall Russell (-160).[3] VSEL's low ratio

[2]Figures for sale prices have been taken from written answers in various volumes of Hansard.

[3]The minus for Brooke Marine comes from it having made a loss in 1984/85 of £1.7m. In contrast the minus for Hall Russell reflects the payment made by the government to the new owners of the yard (however it was maintained that the £16m payment was less than the costs of closure).

(given its monopoly for nuclear submarines) can be explained by two factors: Cammell Laird and Trident. Cammell Laird was in the same position as Swan Hunter; being follow-on yards their futures were less secure than those of the First of Class (FOC) yards[4] (as they could compete for fewer contracts and, when doing so, would be not as far down the learning curve) and this is reflected in the relatively low price for Swan Hunter. Cammell Laird was thought to be even more difficult than Swan Hunter to sell, not only had it made consistent losses it also had difficult labour relations, and therefore was sold in a joint package with VSEL, depressing the price for VSEL. VSEL's privatisation occurred at the same time as the first Trident submarine was ordered and its price was part of the privatisation deal. This price competition led to a reduction of £25m for the first submarine (Q2386, PAC, 1986), though no provision was made for future orders even though no competitive pressures could be brought to bear in the nuclear submarine sector. The MoD argued by achieving a low price on the FOC this could be used as the starting point for negotiations for subsequent vessels. This lower price, combined with a profit sharing agreement of up to £40m, meant the MoD believed its position over the medium term was secure. However this can also be viewed as an example of the MoD's short termism; the MoD, despite being in a position to achieve long term savings given concerns over the cost of the nuclear submarine programme, chose to get a one-off reduction in price with no commitment that these prices could be achieved on subsequent vessels.

Whilst the government was promoting the competition policy espoused in its 1984 Statement on Defence Estimates,[5] the Secretary of State for Defence stated that he had "a competition for the two Type 22s now" (Q63, DC, 1984). This was supposed to be the start of genuine competition between the yards for MoD orders, the tenders for the vessels in a previous round of the competition having expired. By ordering two ships the MoD wished to benefit from a batch order lowering the unit cost but with three yards competing for the

[4] A First of Class yard is one that is able to design and build a vessel whilst a follow on yard is one that can only build the second vessel in a class onwards.

[5] "Wherever possible, however, contracts are placed following competitive tendering and the Ministry welcomes the fact that both specialist and non-specialist shipbuilders have competed keenly for recent orders; we are endeavouring to extend the scope for this" (p23, MoD, 1984).

order (Vosper Thornycroft, Cammell Laird and Swan Hunter) the sign that this was not to be came when the Minister of State for Defence Procurement stated that "one or two yards will be disappointed" going on to mention that the decision "would have many implications for naval capacity" (Hansard, 1179, 68), a reference to Cammell Laird's need to win the order otherwise it would go out of business, and a subsequent statement that price and time would be the primary considerations but "other relevant factors" would also be taken into account (Hansard, 257w, 71). In January 1985 the MoD finally announced it was going to procure one from Cammell Laird and the other from Swan Hunter Shipbuilders despite the cheapest procurement strategy being to purchase both from the same shipyard (Hansard, 21, 72). A simultaneous announcement that Swan Hunter had been chosen to produce a Type 23 subject to contract negotiations (and economies of production were expected) suggests they were the preferred shipyard and ought to have been awarded both Type 22s. By splitting the contract the government was paying a premium of "roughly 5 per cent of the contract price or 2.5 per cent of the total estimated cost of the ships, including bought-in equipment and weapons systems" (Q2736, PAC, 1985.) However this was justified as the process of competition after the initial tenders reduced the total price to below the lowest initial tender. The National Audit Office states the "decision took account of the wider relevant factors involved and offered the prospect of survival of CL [Cammell Laird] as a major warshipbuilder" (para 4.10, NAO, 1985). Although the aim was to ensure sufficient capacity to allow future competition Cammell Laird closed, for the first time, in 1993.

Despite this example of the MoD considering the effect a procurement decision can have on subsequent competitions it is the only example for naval procurement in the 1980s. This would seem to give weight to the alternative theories that Cammell Laird was not awarded the contract for the benefits it could bring to future competition, rather it was due to the Secretary of State for Defence's fondness for Liverpool or to ease tensions after the inner city riots. After the yards had been privatised price competition returned as the sole mechanism by which MoD contracts were awarded with the MoD not being "in the business of providing

orders for any particular yard" (Hansard, 914, 89). Consequently, and as predicted, Brooke Marine and Hall Russell did not remain in the warship sector for long; Brooke Marine sold its warship design rights in 1987 whilst Hall Russell had to call in the receivers in November 1988. Their absence from the sector caused little comment due to the excess capacity that remained.

In the 1987 Royal Navy debate, Members of Parliament complained that yards were running out of work. This had come about for two reasons. The first was the excess capacity that had been created by privatisation left the yards dependent on MoD orders; if all the yards were to have work then each yard would have to have a lower volume of work but the MoD felt no obligation to match its orders to shipyard capacity (Hansard, 447w, 91). The second reason was the government had committed itself to a destroyer and frigate fleet of about 50 in its 1981 White Paper 'The Way Forward' (MoD, 1981). This commitment was subject to much comment in the late 1980s as 'about 50' could mean anything between 45 and 54 and had implications for the ordering rate. If the government were to maintain a destroyer and frigate fleet of 50 and each ship lasts 18 years then 2.8 ships need to be ordered each year (Q474, DC, 1988a). The MoD suggest the life of a ship is 22 years, implying an ordering rate of 2.3 (Hansard, 1244, 128). However these figures combined with the 'about 50' figure gives an ordering rate of between 2.0 and 3.0. A Defence Committee report into the surface fleet (DC, 1988a) bemoaned the lack of orders, with the government increasing the life of ships and not replacing them. In evidence to the committee the shipbuilders argued there were too few orders which, when placed, occurred erratically and that the government had not tackled the problem of excess capacity. VSEL pursued this point to suggest the MoD had an undeclared, and prehaps unintended, policy of maintaining the current industrial structure which resulted in increased costs (through yards being underloaded). The MoD disagreed with this view suggesting in the future the number of yards would diminish leaving them to face a quasi-monopolistic sector but that a competitive sector was the current situation (Q320 and Q321, DC, 1988b).

Any suggestion that the industrial structure was determined by the MoD would be dispelled in the 1990s – future competition was subsumed by short term procurement decisions. However despite predicting an industrial structure which could be detrimental to its interests the MoD took no actions to avoid it. This can be explained either by the MoD's belief that it could protect its interests in these circumstances or that there would be sufficient competition for the reduced number of orders. If the former was the case it questions the need for competition with under loaded firms and suggests the MoD should have sought to fully load the most efficient firms. If the latter case held then the MoD need not consider future competition as the market would adjust to the reduced orders. Although the market would adjust it would not necessarily do so in a way that the MoD's interests would be protected and therefore the likelihood of the MoD intervening in the market ought to have remained; instead the MoD just relied on the market. The MoD was not prepared to take action to avoid a quasi-monopoly; indeed it is possible to argue the MoD encouraged it.

4.2 1990 to 1995

The remainder of the 1980s was, in terms of naval procurement, occupied with arguments over the award of the Auxiliary Oil Replenishment vessel (detailed at the end of this section) and continued concern at the MoD's ordering pattern. By the end of the 1980s the world was changing and the end of the Cold War meant the navy was seeking a new structure. The MoD published an outline of its future plans in 'Options for Change' in 1990. For the Royal Navy this meant reducing the destroyer and frigate fleet from around 50 to around 40, the number of conventional submarines from 27 to 16 and keeping the number of nuclear submarines unchanged at 4. These changes were also to have effects at the industrial level. Despite stating it was likely to be ordering two destroyers/frigates each year (Q364, DC, 1991) the MoD admitted it did not know what the precise impact on industry would be of Options for Change with its smaller orders and shorter production runs. Concerned about competition for orders in the future the MoD said (p34, MoD, 1991):

> From the customer's point of view there is a balance to be struck between the economies of scale that should follow from reduced duplication of research and development and production capacity; and the continuing need for vigorous competition in both domestic and international markets to promote efficiency and downward pressure on prices.

How this balance was to be struck was not detailed but the capacity that was maintained throughout the late 1980s, despite the reduced number of orders, could no longer remain, though the government was not keen on being seen to be behind a programme to reduce capacity. When the Minister for Industry and Enterprise remarked that the relaxation in tension would have a consequent effect on warship yards and "what has happened to Cammell Laird is an instance of that" this was subsequently clarified by inserting a note stating that Cammell Laird was running out of orders before the MoD announced any changes to its procurement programme due to the peace dividend (Q138, TIC, 1990); the problems at Cammell Laird were of their own making and were not caused by the MoD. This stance could not continue and led the Deputy Under Secretary of State (Policy) to comment, "if I was in the shipbuilding industry, I would not regard the prognosis as frightfully good" (Q357, DC, 1991).

Despite its aim of balancing the competing interests of reduced costs against the benefits a greater number of firms could bring the MoD continued to pursue competition as its procurement mechanism with the consequence that little weight was placed on the effect a procurement decision would have on the industrial structure. The procurement of the Landing Platform for Helicopters (LPH) in 1993 was to demonstrate that price remained the main criterion by which competitions were judged and that the short term would dominate the long term. After an unsuccessful attempt to procure the Aviation Support Ship in the late 1980s the MoD used the information gained to develop the specifications for the LPH. Although seven firms expressed an interest in tendering by the deadline in October 1992 only two firms had submitted a bid, VSEL and Swan Hunter. Winning the procurement was important to

both firms: Swan Hunter had recently lost out to Yarrows in the competition to build a batch of 3 Type 23s and the future of the shipyard depended on winning the contract whilst VSEL wanted to re-enter the surface warship building industry (since Options for Change devastated its business plan with the cuts in the submarine programme) and realised "although this was a one boat programme the elimination of Swan Hunters would leave VSEL as the only UK Yard capable of building big ships for the MoD" (appendix 3, PAC, 1994). Despite bidding for the prime contractor role VSEL intended to subcontract Kvaerner Govan to build the ship hull. At this stage VSEL submitted the lower bid by £9 million. As the bids were refined and final bids submitted on 22 April 1993 the price difference increased to £71 million; Swan Hunter's bid increased by £36 million whilst VSEL reduced their bid. The NAO reports that Swan Hunter's bid increased largely as a result of the need to comply with the specification of the MoD. VSEL were able to reduce their bid due to obtaining a better price from Kvaerner Govan (reported to be £6 million by Burton (1994)) and from covering an estimated £20 to £25 million from their reserves in order to re-enter the warship market as a prime contractor (NAO, 4.48, 1993). The Chief of Defence Procurement stated that there was no evidence that VSEL's bid was a result of predatory pricing (as they believed it was possible for the ship to be built for £139.5 million), rather only small contingencies had been built into the bid and therefore should any of the risk of the contract materialise then these would have to be realised from the reserves (Q2, Q3 and Q15, PAC,1994). VSEL announced after the bidding competition they had submitted a "marginally priced tender" with the belief winning "enhanced prospects in the market ... for Royal Navy [ships]" (appendix 5, PAC, 1994).

The final bids were received on 22 April and were immediately evaluated (between 23 April and 25 April) in order for a recommendation to be put to the Equipment Approval Committee the following week. The MoD argued that the difference in price for otherwise similar bids meant the decision to award the contract to VSEL was straightforward. As the MoD was aware of the situation faced by Swan Hunter "although the outcome of the competition was not due to be announced so quickly, the Department considered that any undue delay in

the award of the contract could result in Swan Hunter going into receivership and that, in consequence, the benefits of competition would be lost" (NAO, 3, 1993). The announcement was made to the House of Commons on 11 May 1993. Swan Hunter went into receivership on 13 May 1993. The MoD were aware of the consequences of their choice as they hastily calculated the additional costs to be incurred on other projects at Swan Hunter were they to go into receivership. However the additional costs for the three Type 23 frigates and an Auxiliary Oiler Replenishment Vessel were less than the difference in bids for the LPH (NAO, 4.65, 1993). The attitude of the MoD between current procurement decisions and future competition was given in paragraphs 4.67 to 4.69 of the National Audit Office's report (1993):

4.67 Much has been said about the prospects for future competition should Swan Hunter cease shipbuilding, given the Government's current policy of building warships only in the United Kingdom. The Department has been monitoring the situation for several years and in January 1993 considered that, if Swan Hunter were to close, VSEL might be left with a United Kingdom monopoly for "big ships". The Department also recognised that, whilst the retention of a competitive industrial base required keeping a high level of industrial capacity, the cost of maintaining this capacity – which may be passed on to the Department in prices quoted in competitions – had been more than outweighed by savings from competition. Overall, the Department concluded that these problems could only be addressed in the context of individual procurements and not as part of a wider strategy.

4.68 In considering the potential impact of awarding the LPH contract to VSEL the Department reviewed the implications for future competition, particularly the prospect of running competitions for the larger warships currently in the programme such as the two Landing Platform Dock Replacements. For these vessels, should Swan Hunter cease to trade and with the closure of Cammell Laird, the only military shipbuilder in the United Kingdom large enough to accommodate them is VSEL and then only if the company modernises some facilities at Barrow. This would leave

Kvaerner Govan as the only yard currently involved in the building of large warships. However, there are other possibilities, for example if Harland and Wolff re-enter the naval market or other contenders emerge. If no other contenders emerge, Swan Hunter's close, and Kvaener Govan continue to team with VSEL, the Department could be faced by a monopoly supplier.

4.69 In light of the above, the Department did not attempt to quantify the additional costs arising from a possible loss of competition, for example, on the two Landing Platform Dock Replacement vessels. Whilst more might have been done, the National Audit Office recognise the difficulties inherent in making reliable estimates of the costs that might arise from the loss of competition.

Paragraph 4.67 sums up the lack of a coherent policy for warship building in the MoD in the early 1990s. Despite stating the government had a policy only to build hulls in the UK at a similar time the Minister of State for Defence Procurement declared forbidding prime contractors from exploiting foreign construction of hulls would be "excessively protectionist" (Hansard, 315, 224). Given the MoD was unable to articulate a policy for current procurement the lack of a policy concerning the preservation of future competition was hardly surprising. The paragraph contains the inherent contradiction between successful current and future procurement; despite the success competitive procurement had brought in reducing costs and competition continuing to be the main mechanism of procurement the MoD would not follow a strategy to take actions, where necessary, to preserve competition. This was the justification of awarding the contract for the LPH to VSEL; it was not part of a long term strategy for warship building rather an individual procurement decision taken to minimise the current procurement cost and ignoring the effects on the industrial structure. The First Sea Lord was later to remark that the LPH was purchased at a "remarkable price" and that "no one else in the world could have got an LPH at that price" (Q564, DC, 2005). Whether any other country in the world would have lacked a naval industrial strategy which meant firms had to bid for their survival is another matter. It was the lack of an industrial strategy

combined with the lack of orders that allowed the MoD to gain power from the industry as firms had to bid low in order to win a contract and survive. However this power could only be exercised when the contracts were awarded – after the contract had been awarded the MoD was committed to that one firm and needed them to complete the vessel. The yards, knowing this, would recoup any potential losses associated with the bid price by renegotiating the contract, after specification changes from the MoD, to ensure a realistic price for the vessel (Q75, SCEC, 1998). Paragraph 4.69's assertion that there are difficulties in estimating the costs arising from the loss of competition but that the MoD did not even attempt to quantify them underlines the importance attached to the present by the MoD and the disregard placed on the future.

The possibility of Harland and Wolff or other commercial shipyards re-entering the warship building industry, suggested in paragraph 4.68, is surprising given the experience of the Auxiliary Oiler Replenishment Vessel (AOR). Six firms were invited to tender for producing either one or both AORs in October 1984 but only two responded; Harland and Wolff and Swan Hunter. Both bids were higher than the target price of the MoD (£122 million) and therefore both were asked to revise their bids. Whilst the revised bid of Swan Hunter remained above the target price, Harland and Wolff reduced their bid for the first ship to the target price and the second to £106.5 million. In April 1986 the MoD announced that Harland and Wolff were to build the first AOR (AOR 1) with Swan Hunter given preferential treatment in bidding for the second AOR (AOR 2) providing it was built to the same design and cost as the AOR from Harland and Wolff. AOR 1 was procured under the first whole ship contract so Harland and Wolff were responsible not only for the design and manufacture of the hull but also the procurement and integration of the weapons systems (whole ship procurement was a forerunner of prime contracting). As it was a First of Class a separate contract (valued at £1 million) was awarded to produce the plans so another shipyard would be able to build subsequent ships.

For Harland and Wolff winning the contract was easier than fulfilling its terms. Whilst production was taking place in 1988 the government announced the yard was to be privatised. The process caused uncertainties for the firm and the prospect of closure if no new orders were found lowered the morale of the workforce (5.28, NAO, 1992). Given the circumstances a very substantial proportion of its designers and design engineers chose to resign (Q29, PAC, 1993). As part of the privatisation, which occurred in September 1989, the government agreed to pay the new owners £35.35 million towards the expected costs of completing the AOR 1 and a further £18.07 million to ensure the Northern Ireland Department, the previous owners of Harland and Wolff, had no further commitments to the AOR 1 (Q18 and Q10, PAC, 1991). A further problem was the specification for the ship itself. Although an auxiliary ship it had to meet not only civil standards but naval standards as well due to it carrying vertical launch Sea Wolf missiles and also possessing a helicopter maintenance facility. As Harland and Wolff had not had much recent experience of warship building the NAO (5.33, 1992) suggested the wrong type of contract (a design and build contract) was signed as it meant the design was still evolving at the same time as production. This caused problems when it came to production.

These factors combined meant that by April 1992 AOR 1 was running 32 months behind its planned build of 48 months. Furthermore Harland and Wolff were estimated to have spent £172 million by January 1992. The overall estimated cost to the MoD was around £140 million (excluding the £53 million paid by the Northern Ireland Department). The problems in production were so severe that the MoD stopped making payments to Harland and Wolff twice (April 1990 to May 1990 and May 1991 to December 1992). In June 1992 AOR 1 made its first sea trials, though Harland and Wolff subcontracted Cammell Laird to complete the ship following the sea trials. Although the cost of the ship remained unaltered after this point the in-service date of the vessel slipped further to June 1994.

To complicate matters the contract for AOR 2 was signed with Swan Hunter in December 1987. Due to the problems encountered by Harland and Wolff the MoD were unable to hold Swan Hunter to building it for £106.5 million. Swan Hunter refused to accept a price

below £121.4 million (appendix 1, PAC, 1993). Although the Chief of Defence Procurement recommended a new competition be held as the MoD possessed no reliable information on the true costs of building the ship the Defence Secretary ordered a contract be signed with Swan Hunter (due to concerns about employment in the region (Q6, PAC, 1993)). Swan Hunter encountered difficulties as the plans supposed to be supplied by the lead yard were either delayed or of poor quality (5.29, NAO, 1992). As such Swan Hunter claimed damages against the MoD which offered an 18 week delay for the in-service date to complete the designs to their own specification and estimated to pay total compensation of around £16 million (Q166, PAC, 1993). The ship finally entered service in July 1993, nearly a year before AOR 1 despite being begun twenty months later. The experience of the AORs demonstrated the irreversibility of leaving the warship sector – although some firms did leave only to reenter the market later, for example Cammell Laird and Swan Hunter, they had difficulties in completing contracts due to the gap in production and fell out of favour with the MoD. Consequently the MoD needs to ensure firms remain in the sector as once they are gone it is very difficult for them to reenter and be competitive (in terms of price, time and quality). These difficulties also act as barriers to entry for new firms seeking naval contracts

The reduction in the number of yards caused problems in the procurement of the Landing Platform Docks (LPDs) later in the 1990s. The government started to examine the provision for future amphibious capability in 1985 (Hansard, 162w, 74); despite 'The Way Forward' suggesting there was no need for replacement the Falklands conflict proved otherwise. As HMS Fearless and HMS Intrepid were expected to reach the end of their useful lives in the mid 1990s the MoD thought in 1988 that they had plenty of time in which to reach a decision (Q198, DC, 1988). Not much happened apart from studies until the mid 1990s; the project definition was approved in 1991 but rewritten and reapproved in 1994. Despite aiming to award the contract in December 1995 the MoD were admitting defeat in obtaining a competition for construction; no potential prime contractor was able to secure a partner, either Harland and Wolff, Yarrows or Vosper Thornycroft, to build the hull (Q2007, DC, 1996). The only

option was to negotiate a NAPNOC contract with VSEL. NAPNOC stands for 'no acceptable price, no contract'. These contracts were introduced by the MoD in 1992 to replicate market conditions when no competition could be held. Although the profit and level of information sharing was specified by the 1968 agreement, NAPNOC aims to price the contract before work starts and price according to what could be obtained if there were a market (NAO, 1.9, 2001b). A NAO report into NAPNOC written in 2001 suggested that the outcomes were mixed with variations in both price and time (s8 and s17, NAO, 2001b). For the LPD having to deal with an effective monopoly for the project caused problems; VSEL's original bid was £589m, much higher than the MoD's estimate (para 2.31, NAO, 1996), and the press reported VSEL were not fussed as to whether or not they won the contract due to the other orders it had on its book at the time (Q2008, DC, 1996). Despite the MoD denying the latter negotiations took much longer than expected; 14 months were attributed to refining the project definition to make it affordable and 12 to the extended tendering process (Project sheet, NAO, 1996).[6] The final contract price was £449m, though this included £20m of additional costs for changes to the original specification (all remaining figures in this section from Project sheet, NAO, 1996). Although some of the reductions were achieved by reducing the attributable overheads (though these could probably be charged elsewhere), reduced profit for VSEL and using a mix of naval and merchant standards, others came from increasing the risk to the MoD (the guarantee was reduced from two years to one and limiting the liquated damages to £9m). The lengthened negotiations also caused the MoD to incur run-on costs of £24m. The procurement of the LPDs was made harder by the MoD having to deal with an effective monopoly; as no other firm could undertake the project the MoD was forced to continue its protracted negotiations with VSEL. As it held little power the result was to increase the MoD's exposure to costs and risk. The procurement also highlighted the problem that the MoD, if faced with a monopoly, can only purchase the ships that the shipyard is willing to build.

[6]By 1996 the first LPD was running 41 months late with the other delays being 4 months due to budgetary concerns and 11 months due to extending the build programme.

4.3 1995

The issue of future competition had to be considered by all branches of government when VSEL received two take-over bids in late 1994. Due to the end of the Cold War the MoD altered its programme for submarines by cancelling all its plans for conventionally-powered submarines (3.45, MMC, 1995a). Although VSEL had reentered the surface warship market with the LPH it had not diversified sufficiently or won export orders and consequently thought it would be best placed to do so as part of a larger defence organisation which possessed greater financial resources and the ability to sell overseas (3.76, 5.1 and 5.3, MMC, 1995a). In 1993 British Aerospace (BAe) and GEC Marconi held joint discussions about merging their sea systems businesses with VSEL's but did not proceed due to fears it would not receive regulatory approval following the loss of competition it would cause (3.99, MMC, 1995b); in hindsight they need not have been concerned. Subsequent to these discussions both BAe and GEC Marconi, who already owned Yarrows, made separate bids for VSEL and both bids were referred to the Monopolies and Mergers Commission (MMC) to investigate the effect they would have on competition in the defence equipment market. The methodology employed by the MMC was to consider the effect of a merger with each company on the projects that the MoD were committed to (the final batch of Type 23s, the Batch 2 Trafalgar class submarines (B2TC), the Landing Platform Dock and the Common New Generation Frigate (CNGF) – later to become the Type 45) and see how it would affect the industrial structure. Other projects were considered speculative (even if they were to proceed the manner in which they were undertaken was still to be determined) and not a good basis on which to make a recommendation. It is interesting to note the MMC felt able to quantify the effects that a loss of competition would entail for future procurement, unlike the MoD as expressed in paragraph 4.69 of the NAO's LPH report (1993).

The MMC had little problem with the proposed acquisition by BAe. BAe wished to acquire VSEL to establish itself as a viable prime contractor in the naval market. Although BAe had won the prime contractor competition for an Ocean Survey Vessel despite not owning a

shipyard (and subcontracting the hull to be built by Appledore in the same way as VSEL subcontracted the hull of the LPH to be built by Kvaener Govan) it believed its credibility in the naval market depended on its practical experience of shipbuilding and having to subcontract hulls presented difficulties in winning contracts (5.37, MMC, 1995b). By purchasing VSEL both GEC Marconi and BAe would own shipyards meaning the two main systems houses would own shipyards and be able to engage in effective competition with one another (finally achieving competition between vertically integrated firms that was envisaged at the time of privatisation). One reservation the MMC held was that if BAe acquired VSEL it could withdraw their bid for the final batch of Type 23s and submit a lower one to ensure it won the contest and in doing so effectively close Yarrow leaving Yarrow only able to build the Type 45 FOC. BAe's response was to say that they had never had any intention of engaging in predatory pricing as it "would be a commercially irrational strategy in view of the speculative, long-term and uncertain nature of any advantage which might be achieved" (5.43, MMC, 1995b).

The MMC did, however, have a problem with the proposed acquisition by GEC Marconi. In a majority opinion the MMC ruled it to be against the public interest. The acquisition would reduce the number of potential prime contractors for future projects and place others at a disadvantage as they would be competing against a major integrated systems firm (1.8, MMC, 1995a). The effects of this would be noticeable on two projects: the B2TC and CNGF. Both VSEL (in conjunction with Loral ASIC) and GEC Marconi (with Rolls Royce, British Maritime Technology and AMEC) were bidding for the contract. Even if GEC Marconi maintained the two separate bid teams the MMC were not convinced that effective competition could be retained as senior management would still have to agree the terms of the contract which would give them a monopoly (2.43, MMC, 1995a). The loss of competition would also damage the MoD when it came to procure the CNGF. Although the government was committed to building the FOC at Yarrow batches of follow-on ships would be open to competition from the remaining shipyards. By acquiring VSEL the only competitor GEC Marconi would

face was Vosper Thornycroft. However due to its size Vosper Thornycroft was only able to produce one CNGF every 16 months which, combined with the procurement timetable of the MoD, meant they would only be able to produce half the total order leaving GEC Marconi with a guaranteed monopoly on half the ships unless the MoD's plan was changed (2.48, MMC, 1995a). The result of the loss of competition would be higher prices both directly as a result fewer firms competing for the contract and indirectly as firms would be more secure of gaining future work there would be less effort directed towards increasing efficiency (1.8, MMC, 1995a). The MMC also raised fears that there would be problems in the subcontractors market with the possibility that GEC Marconi would favour its own subsidiaries (1.10, MMC, 1995a).

The view of the MoD towards who it would favour succeeding in acquiring VSEL was one of indifference; although acquisition by GEC Marconi would reduce competition it would not eliminate it and, given that competition would be reduced anyway due to overcapacity and insufficient orders, there was no reason for the MoD to object (6.71, MMC, 1995a). Furthermore the MoD, through being a government department, was able to protect itself from exploitation when competition was imperfect and was able to apply competitive disciplines in negotiating the contract and verify costs after production (6.26, MMC, 1995a).[7] As such even if a monopoly were to occur it would not affect the value of the contracts placed – GEC Marconi winning would not affect the ability of the MoD to achieve value for money (D6, MMC, 1995a). Given what its sole source contracting techniques (NAPNOC) could achieve the MoD also considered it possible to obtain better value for money by having one well-loaded source as opposed to two competing underloaded sources due to the reduction in fixed costs and that this gave rise to a "practical view of competition" (6.27, MMC, 1995a). The costs of maintaining competition in a declining market were therefore considered to be hard to justify (6.71, MMC, 1995a).

[7]As mentioned previously a NAO report into non-competitive procurement by the MoD descried the outcomes as being mixed (NAO, 2001b). The MoD has always held a greater belief in its ability to price contracts than evidence suggests it should have.

The MoD's position was accepted in a minority opinion by two of the six members of the MMC committee. The dissenting opinion argued that the MoD was a monopsony with considerable power that can create competition if it does not exist (this option being described by the Treasury as being "at best unproven, if not optimistic" (6.93, MMC, 1995a)) or impose competitive pressures when none would otherwise occur (D6, MMC, 1995a). The dissenting opinion suggested that these pressures could be: threat of foreign competition (though elsewhere in the report the MoD rules this out due to a lack of reciprocity, concerns over future support for the ships, problems with intellectual property rights, security concerns, possible increased training costs (6.73, MMC, 1995a)); auditing costs after the project has been completed (but this does not create the incentive to increase efficiency in production); threat of withdrawing contracts from those firms that perform poorly (but if the MoD is already faced with a domestic duopoly then it is difficult to allow the creation of a monopoly and impossible to close the remaining monopoly); benchmarking costs against other firms (obtaining like for like price quotes is very difficult in the defence sector); and policing subcontract competitions (which defeats the purpose of prime contracting which is to place more control in the hands of industry). With regards to the B2TC contract by not maintaining competition as the MoD desired GEC Marconi would be risking its relationship with the MoD and would "amount to little less than commercial lunacy" (D7, MMC, 1995a) but as it would hold the monopoly the government would be reliant upon it. With regards to the CNGF although it has a monopoly for half the ships due to the excess capacity in the combined firm it would bid competitively for all of the batches (D23, MMC, 1995a).

Accordingly the Secretary of State for Trade and Industry had to decide whether or not to allow the bids to proceed. The decision was announced on 23 May 1995 that both bids had been allowed to proceed. As "the MMC obviously reached a narrow decision" on an acquisition by GEC Marconi and the MoD believed "it could handle the competitive issues involved in the process" the Secretary of State felt empowered to overturn the majority MMC decision (Hansard, 725 and 726, 260). GEC Marconi won the competition for VSEL meaning

the only competition it faced for naval contracts, given it already owned Yarrows, was Vosper Thornycroft. The MoD's indifference was surprising as it had the opportunity to have two major vertically integrated defence firms able to compete for naval contracts, an original aim of the privatisation of British Shipbuilders, yet expressed no desire for this outcome. Vosper Thornycroft would only be able to provide competition for small ships, and even then only if the batches were not too large.

Whilst the MMC was deliberating the government announced an update to its procurement policy in the 1995 Royal Navy debate. Although the government congratulated itself on the benefits increased competition had brought it went on to announce an evolution of its procurement principles was needed to reflect the change in circumstances (the permanent end of the Cold War and consequential reduction in the equipment programme). The six principles outlined were: retention of capability to build hulls, work to be undertaken in the private sector, value for money, security of supply, awareness of the impact decisions have on other military technology and pursuit of collaboration with Europe (Hansard, 1154 to 1156, 254). The description of value for money for the first time acknowledged the effect decisions can have on future competition committing the MoD to give "due consideration to the possible consequences of any procurement decision for the defence industrial base" (Hansard, 1156, 254). The opposition replied that this amounted to the MoD recognising "there might be a need for something called an industrial policy" (Hansard, 1164, 254).

The absence of one was the noteable feature of the evidence submitted to the joint defence and trade and industry committees' inquiry into defence procurement and industrial policy (which also occurred in 1995). Whilst the Defence Manufacturers Association described the procurement policy as "verging on the hostile to the indigenous industrial base" (Ev 3, DC, 1995) and went on to say the "uncompromising pursuit of competition largely excludes concern for the social and long term economic or political penalties occasioned by an unstructured rundown of the national UK defence industrial base" (Ev 4, DC, 1995) the more common reaction from industry was industrial considerations were opaque so that when they came

to the fore it meant ad hoc decisions were being taken. Further there was a feeling the MoD had no accountability for the defence industrial base and had no desire to take on the responsibility. GEC Marconi referred to the MoD's benign neglect and reliance on market forces but warned "where there is a single customer, capacity greater than demand, and only 2 or 3 suppliers, there is not competition in the true sense" (Ev34, DC, 1995.) The MoD took a "pragmatic" view which meant that it was for industry to respond to the reduced naval orders by restructuring rather than the MoD allocating orders to obtain a desirable industrial structure (Q341, DC, 1995). Given the loss of Swan Hunter it would be "a matter of concern" to the MoD if a duopoly became a monopoly (Q345, DC, 1995) but it re-iterated that it was able to maintain competition with only two firms present (a view first expressed in 1985).

The committee accepted the arguments put forward by both VSEL, that the Trident programme was a success despite being undertaken by a monopoly, and the MoD, that one well loaded source is better than competition between two under loaded sources. Accordingly they recommended that rationalisation in the defence industry should not be discouraged by fears of losing competition and that a monopoly could be appropriate for certain sectors of the defence base (para 79, DC, 1995). Another inquiry followed in 1998 which reported the industrial considerations involved in a procurement decision were now being considered but industry still felt too little weight was attached to them. The MoD countered that the effects of procurement decisions are important for long-term value for money and that they had issued formal guidance to staff requiring them to assess industrial consequences of any procurement decision and to consult the DTI if a procurement contract for production was worth over £15m (Q165, Ev38 and Ev46, DC, 1998). Contemporaneously the Select Committee on the European Communities called for state aid for commercial contracts be opened up to all shipyards. In evidence industry stated that bids for procurement contracts were entered knowing that the vessel could not be built for that price but instead the firms would rely on changes to the contract to renegotiate a more realistic contract (Q75, SCEC, 1998). The reduction in the number of shipyards meant the government had to support those that

remained in any way it could if there was to be competition for the MoD's naval procurement programme.

The government presented the defence procurement debate in October 2000 as being a renewed halcyon period for the shipbuilding industry with "the largest programme of warship construction that this country has ever seen in years" (Hansard, 419, 355). An alternative view is these were the first major warship orders since the change of government in 1997 with the MoD having little control over where to place the orders. The six roll-on roll-off (ro-ro) ferries had to be procured outside article 296 as they were designated commercial vessels not to enter any war zones.[8] Although the MoD could not limit the competition to UK yards they asked those planning to build overseas demonstrate they could not use UK yards and be as competitive. The winner was Andrew Weir Shipping who were awarded a £950m contract to build and operate the six vessels for 25 years. They chose Flensburger in Germany to be the lead yard and build four whilst Harland and Wolff were to build two. These being non-war vessels meant Harland and Wolff were able to build them, though not without commercial problems. Whilst the MoD were constrained by the European Union's competition rules in their procuring of the ro-ros, when awarding the contract for the two alternate landing ships logistic (ALSL) the constraint was the MoD's own future programme. Although Swan Hunter won the competition to be the lead yard and build the first two a further contract for another two vessels was to be negotiated with BAe Systems to be built at Govan. The government explained the two extra were to be built at Govan to shorten their in-service date though this ignored the learning curve effect that could be exploited at Swan Hunter. It also ignored the time slippage on the Type 45 project (detailed in the next section) which meant Govan was running out of work causing redundancies and uncertainty over the future of the yard. Although the next construction at the yard was to be the Type 45s delays meant the yard was to face a gap in production which the ALSLs would partially solve – although there would be an eight month gap in steelwork this was sufficient from the firms' viewpoint. If

[8] Article 296 of the European Union Treaty (previously article 223) gives member states the power to specify domestic, non-competitive production of certain goods of which war equipment is one.

Govan had not been awarded the two ALSLs then there is the possibility the yard would have irreversibly closed, with the loss of a shipyard capable of constructing large ships. The reduction in the number of yards meant the MoD was restricted in achieving value for money as it was forced to consider the forward programme. The lack of attention previously given to the naval industrial base was, by the turn of the century, finally starting to affect the MoD.

4.4 Type 45 Destroyer

In January 1988 the government announced its participation in the NATO Frigate for the 1990s (NFR 90). This was a collaborative procurement project with Canada, France, Germany, Italy, the Netherlands, Spain and the US. The UK withdrew from the project in 1989 as the joint procurement was causing difficulties: different countries had different budgets and therefore could afford different ships whilst there were also disagreements over which AWW system to use, the choices being between a US system and a European system (Q35, DC, 1999). As the partner countries were unable to agree upon a specification the project failed and countries were still left with a requirement to procure an appropriate warship. The UK and France, later joined by Italy, decided they had similar requirements and decided to jointly design and procure a warship whilst Germany, Spain and the Netherlands did likewise. The UK had plans for 12 ships, France for 4 and Italy for 6.

Memoranda of Understanding between the British, French and Italian governments were signed in July 1994 and March 1996 on two programmes: Horizon and PAAMS. These two programmes were to combine to form the Common New Generation Frigate; PAAMS was the principal anti air missile system and Horizon the ship and its other systems. The Royal Navy planned for the new ship to replace the Type 42 destroyers. In April 1999 the Horizon programme was terminated after the end of phase one (project definition and initial design phase) due to cost-effectiveness concerns, delays to the in-service date and the lack of a prime contractor (Q19, PAC, 2001). The budgetary concerns stemmed from each country's requirements being built into the one design and inefficiencies in undertaking the contract

(Q4, DC, 1999) whilst the timetable concerns arose from the in-service date of the FOC being delayed by 33 months at the time of the cancellation of Horizon (though 30 months were attributed to delays in PAAMS which affected Horizon due to the alignment of the programmes (p.66, NAO, 1999)). The lack of a prime contractor was caused by the complex industrial structure of the company created to administer the project, Horizon International Joint Venture, which was a consortium of the French DCN, the Italian Orizzonte and the British firms GEC Marconi, BAeSEMA and Vosper Thornycroft (though the last two were involved to a much lesser extent). GEC Marconi's offer to be the lead company (p.55, DC, 1999) was rejected by both the French and Italians (p.59, DC, 1999). Consequently the lack of a prime contractor able to bear the risk meant an appropriate contract, both in terms of price and performance, could not be offered to all the countries involved. Although the Horizon project came to a close it was agreed the PAAMS programme would continue. The British government, still needing a replacement for the Type 42, established a programme for a new warship giving rise to the Type 45 destroyer programme.

The MoD announced Marconi Electronic Systems (MES) as the prime contractor for the Type 45 in November 1999 having already given a commitment that Yarrow would build the UK's FOC. After the merger of MES with BAe (to form BAe Systems) the prime contractorship passed to BAe Systems Electronics. The Chief of Defence Procurement (CDP) stated there were three places able to build the Type 45: Yarrow, Barrow and Vosper Thornycroft (Q45, DC, 1999). With the first two now in the same company competition was effectively limited to BAe Systems at Yarrow and Vosper Thornycroft. For once concerns over future competition arose, though only for the remainder of the class and not for naval procurement in general. The MoD chose to order its ships in batches and expected the price to decrease with each batch due to the learning curve; there was a 36% decrease in the price of a platform for the last Type 23 when compared to the first (4.67, MMC, 1995b). However the price would only decrease if there was an effective competition for all the batches; there were three or four firms competing to produce the last four batches though only Yarrows and Swan Hunter won

(and both had had a one ship contract towards the start of the programme, Yarrow producing the FOC and Swan Hunter the second). A similar learning curve was also evident in the procurement of the Sandown minehunter (with Vosper Thornycroft winning both follow-on batches competing against Yarrows who produced the FOC, the unit price of the first follow on batch was 13% lower than the FOC (4.67, MMC, 1995b)). The identity of the winner of a procurement competition to produce a batch of ships was not viewed by the MoD as being important so long as another firm would be able to bid competitively against it for the next batch. Even though Vosper Thornycroft had not produced a steel-hulled warship since for the MoD since the early 1980s the MoD was relying on them to provide the competition. However the CDP felt under no compulsion to give Vosper Thornycroft orders in order to sustain the yard (Q50, DC, 1999):

> I agree that it is a proposition [the yard closing if it is not awarded work] but it is one that was put to me about the last Type 23 order which Vospers did not win. I cannot remember an occasion when somebody faced with perhaps not securing an order did not make some very pressing industrial points about the cataclysmic consequences that would occur if we failed to give them the order.

The MoD proposed to ensure competition would be possible on follow-on batch orders by giving Vosper Thornycroft a contract for a steel-hulled trimaran and ensuring Vosper Thornycroft played a role in the design team for the Type 45 to ensure they would be able to build it (Q257 and Q262, DC, 2000). They also expressed interest in Vosper Thornycroft being allowed to build some of the blocks of the vessel and then ship them to Yarrow on barges so they would not only have experience of the design but also of the manufacture (Q262, DC, 2000).

After the initial design work BAe Systems Marine and Vosper Thornycroft formed an 'Alliance' to jointly bid for the production contract with both being involved in the design and production. In July 2000 it was announced that the 'Alliance' was to be awarded a production contract for three ships; effectively each company was to produce one and a half

ships (with BAe Systems joining the third ship). This would mean both companies had knowledge of production and would be able to compete against one another to produce the remaining nine ships, offered in batches of three.

In December 2000 BAe Systems made an unsolicited offer to manufacture all twelve ships at a cheaper per unit cost. It was an interesting offer given BAe's submission to the MMC when it attempted to purchase VSEL in 1995, namely that predatory pricing would be a speculative and irrational strategy. In the words of the then Chief of Defence Procurement the offer "attached certain conditions about other programmes in order to generate cost savings ... if virtually all warship building activities for ever and a day went into BAe Systems Marine, everything would be great for us in the long term" (Ev5, DC, 2002). As a result of this offer and an inability for the two firms to agree terms on risk-sharing and price the MoD asked the RAND corporation to act as consultants and to assess the procurement options open to them. The decision to call in consultants highlights the lack of a coherent naval procurement programme which took into account the industrial structure – that the MoD foresaw the monopoly the proposal entailed but was unable to internally undertake the analysis itself (harking back to para 4.69 of the NAO LPH report (1993)) and reject it for going against its procurement philosophy and, in all likelihood, increase the costs of future programmes. However the unsolicited bid meant the question of the warship industrial structure was finally being asked by the MoD and others.

Whilst RAND undertook their study of the proposal itself, despite its superficial attractiveness, came under criticism. In a Westminster Hall debate it was attacked as "low commerce" (Hansard, 261wh, 363) as the procrastination caused by the unsolicited offer meant Vosper Thornycroft was running out of work placing their ability to remain in business and participate, should the original plan resume, in danger – it had previously subcontracted work on two survey vessels to Appledore in the expectation of commencing work on the Type 45s. The criticism was not directed at BAe Systems, as they were pursuing a commercially sensible policy of "seeking to develop a long-term warship building strategy in partnership" with

the government, where partnership was defined as BAe Systems being awarded the work on all the Type 45s, Astute submarines and possibly 2 oilers (BAe Systems company brief as reported in Hansard, 265wh, 363), but at the government. The government was risking future competition for short term gain jeopardising its commitment to competition in defence procurement. As this was a debate on shipbuilding on the South Coast there was pressure on the MoD to reject the proposal and return to the split production originally envisaged to ensure Vosper Thornycroft's survival. In his reply to the debate the Under Secretary of State for Defence repeated the familiar statements that MoD's orders alone would not be able to sustain all the shipyards, the MoD's interest in maintaining a competitive shipbuilding industry and the MoD's primary procurement concern being to purchase the best equipment at the best price (Hansard, 274wh and 275wh, 363). It is the word "however" which linked the last two statements that suggests short term views could still take precedence despite the original procurement strategy for the Type 45s taking a longer term view (through the life of the programme). The gap in production led to Vosper Thornycroft building three River class vessels for the MoD, though rather than the MoD buying them the vessels are leased under a service contract with Vosper Thornycroft retaining ownership of the vessels.

The focus of the RAND study (Birkler et al 2002) was to compare the additional costs associated with having two firms undertake the production against the benefits of competition that two firms can bring. The quantitative work was concerned with the Type 45 project. As a result of the research the procurement strategy was changed to a modular system. Vosper Thornycroft is to produce two of the six blocks (blocks E and F) and the masts whilst BAe Systems will produce the remaining blocks and assemble them. Although this strategy ensures both BAe Systems and Vosper Thornycroft are present in the industry throughout this decade, though the authors mention a concern that block production might not be able to keep Vosper Thornycroft with the facilities to build complete ships in the future (some skills for some blocks might be lost). In considering the long term effects of this decision on the market structure Birkler et al (2002, Appendix B) calculate competition for ship and

missile production programmes reduces costs by about seven percent. They add that an uncompetitive industry has a higher rate of price escalation (estimated to be 1.7 per cent above consumer price index). When the future was undiscounted the implication of having only one firm in the industry was higher project costs from 2021 onwards (at this point the benefits of there being only one firm are outweighed by the lack of competition). When the future was discounted at a rate of four per cent (approximately the government's discount factor) the break even point was extended to 2026.

Accordingly the MoD rejected BAe's sole source offer and announced that the construction of the first three ships was to be shared between the two companies as it "looked a good way of keeping two companies in the warship building business" (Q9, DC, 2003), however this commitment to future competition was tempered by the CDP finding it difficult to rationalise forgoing competition today in order to have competition tomorrow (Q13, DC, 2003). BAe Systems responded by announcing 1150 redundancies. In response to this the Scottish Executive established the Clyde Shipyards Task Force to examine the future of the industry and how to deal with the unemployment generated. Recommendations 7 and 8 suggested the government continue to consider industrial factors in procurement which led the MoD to reply that this was "consistent with current government policy" (Ev9, SAC, 2002) but that competition would remain at the heart of the procurement policy and that "the MoD order book alone cannot be expected to sustain the UK shipbuilding industry" (Ev4, SAC, 2002). However the MoD accounts for 85% of the shipbuilding industry and evidence given by BAe Systems stated they had no interest in competing for commercial contracts as they did not offer a sufficiently high return (Q94, SAC, 2002). Although the MoD might not have wanted to be responsible for the industry in reality it had no choice. Vosper Thornycroft were more positive and confirmed their plan to move from Southampton to Portsmouth by leasing a shipyard for 100 years. The MoD has subsequently increased the order to six ships, to be built by the alliance, but has ruled out procuring four of the remaining six. The MoD was to later state that the procurement strategy "replaces competition for the later batches of that

class with a strategy which allows competition for further programmes" (Q141, SAC, 2002). The delivery of the FOC has already been delayed to May 2009; the delays are expected to cost the MoD an additional £10 million per vessel a year (Q42, PAC, 2000). The procurement difficulties encountered in the Type 45 procurement exemplify why the MoD needs to have a defence industrial structure that it can support through its procurement programme. The lack of one meant a quick and coherent response to the unsolicited bid was unavailable causing further delays to the programme itself with alleged security implications for the UK.

4.5 Future Aircraft Carrier

By the turn of the millennium the MoD was faced with the prospect of monopolies in various sectors of the defence industry as a result of its policy of unfettered competition. Furthermore in most areas that monopoly would be BAe Systems. If the MoD were to continue to use competition as the mechanism of placing procurement contracts then the rules of competition would have to be altered to allow for future competition. In 2002 the MoD published the Defence Industrial Policy (MoD, 2002) which was the first document published that referred to the effect current competition can have on future competition. It altered defence procurement in two ways. The first was to define what a British company is for the purposes of the domestic defence industry. It redefined a British company from a definition based on the ownership of the company to a definition based on where the jobs, investment, skills, technology and property rights reside. Therefore if a French state owned firm has a subsidiary in the UK then that subsidiary would be treated as a British firm when awarding contracts. The second was to list factors that should be considered when making procurement decisions, meaning price was no longer to be the sole determinant. While the list included value for money (with whole life costs and risk being considered) and the maintenance of certain resources for national security reasons it also included long-term value for money which was described as (Table 1, MoD, 2002):

> Long-term value for money is wider than that for individual projects. Competition is

> MoD's primary means of achieving value for money, and any decision which would impact on the ability to compete future requirements – for example, by creating a monopoly at prime or even sub-contractor levels – needs to be considered very carefully.

The document goes on to state that procurement decisions can no longer be viewed as isolated events, rather a decision on one project can affect the performance of others. Whilst acknowledging the link between competition and potential industrial consolidation the policy fails to recognise that these considerations need to be taken into account for all projects; when the time is reached where one contract can create a monopoly the MoD is unlikely to be able to use competition as a mechanism to award contracts again. Either the contract is placed following competition where a monopoly awaits or the contract is placed non-competitively to preserve competition with subsequent contracts, most likely if the potential monopoly remains the most efficient, placed similarly giving the firms, assured of their future existence, no incentives to submit competitive prices.[9] Thus for the policy to be effective future competition has to be considered with all contracts, not just those with immediate effects. However the policy of not intervening directly in the market to determine a desirable industrial structure remained with the objective being for industry to restructure itself around MoD requirements.

Although formal guidance was issued, again, to staff stating the need for industrial considerations to be part of the assessment process industry still complained that no specific weights were to be given to these considerations when making the final decision. The problem associated with the lack of weighting guidance came to the fore when the MoD had to choose, on behalf of the Royal Air Force, between BAe System's Hawk and the Italian company Finmeccanica's Aermacchi. BAe Systems claimed MoD officials proposed purchasing the Italian plane on cost grounds but had to be overruled by a ministerial directive (Q2, DC, 2004) whilst the Chief of Defence Procurement denied recommending a specific aircraft (Q114, DC, 2004).

[9] An alternative procurement strategy to competition to deal with these problems is outlined in the next chapter.

Ultimately it was the Hawk that was purchased; although half the Cabinet, according to press reports, preferred the Aermacchi as it was cheaper the other half argued the Defence Industrial Policy should be adhered to and the unemployment consequences of not awarding the contract to BAe Systems more than recouped the extra cost. The purchase of the Hawk was the first test of the Defence Industrial Strategy, that factors other than life-cost could determine the procurement decision. It was against this document that the CVF was procured.

The Strategic Defence Review announced the MoD's plans to replace their three Invincible class aircraft carriers with two new larger vessels in the second decade of the new millennium. The Future Aircraft Carriers (CVF which stands for Carrier, Vehicular, Future) were set provisional in-service dates of 2012 and 2015. In 1999 six firms were invited to bid to become prime contractor with only two responding: Thomson-CSF (now Thales UK) and BAe Land and Sea Systems (now BAe Systems). The procurement process was altered at the request of the firms during the course of 2002 to reduce the level of risk associated with the project. In November 2002 designs were submitted with the MoD planning to announce a single preferred contractor at the start of 2003.

Thales is a French company with the French government possessing a 32% share in it. In 2000 the company, then Thomson-CSF, acquired Racal Electronics plc and the remaining shares in Shorts Missile Systems and Pilkington Optronics. This expansion into the UK market followed the merger of British Aerospace and Marconi Electronic Systems and was encouraged by the Ministry of Defence as it created a second major defence firm in the UK, one which is able to compete with BAe Systems for prime contractor status in defence electronics projects. Although Lockheed Martin were also able to compete they had no manufacturing capability in the UK (Q292, DC, 2000). To welcome Thales the deputy CDP was seconded from the MoD to the company for two years with the aim to inform Thomson-CSF of how the MoD carries out procurement and to ensure any concerns about security could be dealt with (Q291, DC, 2000). In the summer of 2002 Thales warned that it would review its strategy if it did not win some of the major forthcoming projects as it had won none in the previous two years;

the CVF was one of the projects being alluded to.

Whilst the government were welcoming to Thales its relationship with BAe Systems was souring. This was due, in part, to two other projects which were causing problems. The Astute Class submarine was designed to replace the Swiftsure and Trafalgar class. Originally the order for 3 submarines was placed with GEC Marconi (with Britiah Aerospace providing the competition), however the programme was running behind schedule and over budget. Currently the programme is running 43 months behind schedule with cost increases of about £680 million (around 35%). The Nimrod MRA4 is a maritime patrol aircraft which was due to be in service by April 2003 but due to delays is now expected to be in service by September 2009 (a delay of 77 months). Whilst the number ordered fell from 21 to 18 (this being announced simultaneously with the reduction in the order for Type 45s) the total cost increase was around £780 million (around 28%). Discussions between the MoD and BAe Systems as to who was liable for the delays and costs continued as the government was deciding which firm was to be the prime contractor for the CVF. The outcome, announced in February 2003, was for the government to increase its funding by about £270 million for the Nimrod MRA4 and by about £430 million for the Astute. Meanwhile BAe Systems had to fund £760 million of the costs, of which roughly £250 million was attributed to the Astute.

Shortly before the announcement for the prime contractor of the CVF the Defence Secretary stated that BAe Systems could no longer be regarded as a British company since "the majority of shares are no longer owned in the UK" (The Independent, 16/01/03). As this was offered as an answer to a question concerning whether BAe Systems would have a political advantage over Thales the interpretation given to this remark was a prediction that Thales would win the contract. The following week BAe Systems made 700 people redundant at Barrow, 265 amongst the Clyde shipyards and a further 80 in other divisions due to a shortage of work in the order book. However BAe Systems denied it being a signal regarding future trends in employment in the shipyards if they did not win the prime contractor status as the lead-in time for production for the CVF would be too long to alter the situation. Simultaneously

the fact that Thales was subject to legal proceedings for copyright infringements by a South African firm which was claiming damages after Thales was subject to allegations of bribery were levied in the press.

On the 30th January 2003 the Secretary of State for Defence announced to the House of Commons that the procurement would be undertaken by a partnering approach with BAe Systems, Thales UK and the Ministry of Defence as partners. Although BAe Systems was designated the prime contractor as the links between the shipyards and BAe were to be exploited in production, the design of Thales was preferred – this was not overly surprising given the preponderance of ex-MoD naval designers reported to be on the Thales bid team. Accordingly the MoD expected Thales to receive around a third of the contract which was then estimated to cost £2.9 billion. The consensus on the decision at the time was the government had split the contract as it was unable to weather the political consequences of making a decision; if Thales did not possess the French connection then they would have won the prime contractorship. The procurement minister stated: "We want to get the best possible carriers for the best possible value and on time. This solution gives us the best chance of getting those things." (The Independent, 31/01/03)

Partnering is a concept that has been imported from the construction and energy sectors where, although no precise definition exists, it is taken to mean the principal and agent collaborating to achieve a goal to the benefit of both. The concept first appeared in the Treasury's 1995 document on procurement and has been refined several times by the MoD since.[10] The perceived benefits from partnering are: a focus on achieving value for money rather than the lowest cost, increased opportunities for innovation, a fair division of the risk (pain/gain shares), a move from the adversarial nature of competition to a more constructive relationship reducing disputes and litigation, a greater flow of information between the MoD and industry, increased stability through the use of longer contracts and better long-term value for money (MoD, 1998). Further a NAO report into partnering in the construction industry

[10]The three documents are: MoD Guidelines for Industry Number 4 – Partnering between MoD and Suppliers (1996), Partnering Agreements between the MoD and its Suppliers (1998) and Smarter Partnering (2002).

reports that project (one-off) partnering generates savings of between 2 and 10 percent whilst strategic (long-term) partnering saves up to 30 percent (para 2.3, NAO, 2001a). The NAO state value for money should be achieved if: the partners are appointed by competition, targets are set for continuous improvements, appropriate incentive structures are set and open book accounting is undertaken. In the same way the MoD enthusiastically embraced competition in the 1980s and 1990s it has done so again with partnering in the 2000s. A recent NAO investigation into the MoD's project control (NAO, 2005) received a presentation where the MoD set out the benefits of partnership (trust, understanding, flexibility, value orientated, joint-team approach, innovative, can-do and collective focus on price, time and capability) whilst the disadvantages of competition, or arms length procurement, were the diametric opposite (respectively distrust, secrecy, frustration, win/lose deals, antagonism, time slippage and financial loss).[11] However by placing trust as a benefit of partnership suggests a misunderstanding of the technique as the collaboration can only be successful if there is trust between the parties to enable them to work together effectively and engage in open book accounting. Despite the evangelical rhetoric about partnering from the MoD, without the required trust underneath partnering is doomed to fail. In a review on the literature on partnering in the construction industry, Fisher and Green (2001) point out that despite partnering being used by the construction sector for ten years there are no verifiable benefits in published papers attributed to it, although managers have been reported to praise it. Other problems with partnering include a too cosy relationship between the two parties which prevents value for money being achieved (by anti-competitive behaviour) and exploitation of the gains by only one of the partners. Given the reduced number of shipyards able to complete naval contracts competition was becoming increasingly difficult to undertake thus partnering offered a new procurement mechanism which reflected the lack of competition the MoD had managed to maintain.

[11]Slide 31, www.naodefencevfm.org/downloads/fist_nao_presentation_jul_04.pdf).

The MoD has interpreted partnering as a new way of doing business but does not seem to have given an explanation as to why this approach is now preferred. Whilst the move away from the adversarial relations with industry in the past is an improvement the government, unlike construction clients, never used litigation for poor performance preferring to place liquidated damages clauses in contracts instead. The other advantages cited by the MoD were also already in place: by this stage it had already been established the focus should be on value for money over the life of the project rather than the initial procurement price, the culture of procurement had changed with the introduction of Integrated Project Teams as the organisational boundaries between the MoD and industry became blurred with both working as a team on projects to make efficiencies and increase communication and the MoD did not enforce contracts when the initial risk judgements were wrong preferring to renegotiate contracts to share the risk. One advantage, paradoxically, of partnering was to enable the MoD to regain from the firms some of the power it had lost over the years as the MoD was now involved in the planning and development of industry's responses to its needs whilst still being able to transfer the responsibility of manufacture; it could respond sooner to problems and find resolutions rather than letting the project go wrong and then having to renegotiate the whole contract. Given the increase in the forward programme withholding contracts will no longer be possible meaning the MoD has no route through which it can regain power from the firms.

The MoD's optimism surrounding the award of the CVF contract proved to be misplaced within days. Although the Thales design was preferred BAe Systems stated it was responsible for running the design team. (In the bids BAe Systems had proposed building the ships in three sections whilst the Thales design called for five). Further BAe Systems reportedly divided the project into six parts with Thales only appearing in the design category as one of the firms involved with the design. As this was not a third of the project the explanation given was that Thales would only manage a third of the project and not receive a third of the work (The Observer, 02/02/03). An alternative theory as to why Thales was awarded

one third of the work was the French are looking to build one new aircraft carrier so if the two countries were to collaborate by juste retour British firms would receive two thirds of the work whilst French firms receive one third.[12] A Memorandum of Understanding was signed between the two governments in March 2005 to work together to see if there are any benefits from cooperation.

By the end of the year the problems of the partnership approach were apparent for all to see. The press reported the cost had increased to £4 billion so the MoD demanded it be reduced. This was achieved by reducing the weight of the ship from its original 65,000 tonnes by 10,000 tonnes, reducing the number of aircraft to be carried by 15 to 35 and reducing the ships length from 295 meters to 265 meters. Even these changes to the specification still left the cost at over £3.5 billion. The arguments concerning the design of the ship and associated cost suggested the April 2004 date for agreeing the final design and budget of the ship was unlikely to be met. This date was important; in evidence to the Defence Select Committee in 2001 the Chief of Defence Procurement stated the MoD was going to stick to its timetable in order for the 2012 in-service date to be met (Q53, DC, 2001). Although the timetable was slipping the MoD offered the excuse that more design work was being done up front so time should be regained later in construction (by December 2005 the design was 60% complete (Q534, DC, 2005)).

Whilst discussions about the CVF continued there was continued speculation about possible mergers in the defence industry. BAe Systems was looking to expand and gain influence in the US. At the same time there were also thoughts of European mergers involving BAe Systems, Thales and EADS. A possible merger between Thales and BAe Systems was rejected by both in June 2003 at informal talks with BAe Systems preferring to merge with a US company (Boeing, Lockheed Martin or General Dynamics were all mentioned at one time or another). It looked as though Boeing was the most likely firm for it to merge with when its chief executive Philip Conduit stated in summer 2003 they might be interested in BAe Systems.

[12]With the introduction of OCCAR juste retour no longer applies on individual procurement rather across a range of procurement projects of the signatory countries.

However in the spring of 2004 Boeing had a new chief executive after an 'ethics' scandal. Harry Stonecipher, the new chief executive of Boeing, stated he was "not interested in being in submarines or shipbuilding" (The Independent, 02/03/04) – the view was that BAe Systems was now too vertically integrated to be of interest, despite vertical integration being one of the aims for privatising British Shipbuilders originally.

Following this BAe Systems announced it was seeking offers for its warship yards. Although it never formally placed them for sale General Dynamics were reported to be interested in purchasing Barrow. However due to the national champions argument it is doubtful whether the government would allow them to be sold to a foreign company. This would have left Vosper Thornycroft as the company most likely to purchase them. This was in April 2004, the same month the final decisions regarding the CVFs were due to be taken. By this stage the discussions had broken down. The MoD ended the partnership between Thales and BAe Systems and instead instigated an alliance involving BAe Systems, Thales and the MoD (in essence a more contractual relationship between the parties than occurs under a partnership).[13] Concerned by BAe Systems' lack of commitment to the industry the government announced that it was considering a long term strategy for distributing its contracts for ships (not only for the CVFs but also for planned auxiliary support ships). In October 2004 the government held a meeting with the shipbuilders at which they proposed the firms worked together rather than in competition with one another. The proposed idea was for the work to be distributed between yards in a manner that ensured their survival. The firms involved in the discussion are BAE Sytems, Babcock (owners of the Rosyth shipyard), Rolls Royce, Vosper Thornycroft, Swan Hunter and DML (owned by Haliburton KBR (51%), Balfour Beatty (24.5%) and The Weir Group (24.5%) and which owns Devonport Dockyard and Appledore shipyards). The talks are currently in difficulty as they cannot agree how to value assets going into this new partnership, whilst BAe Systems refuse to include its submarine business.

[13]The MoD's share of the project was 10% (Q96, DC, 2004).

When the Geddes commission was investigating British shipbuilding in the 1960s there was the prospect of new aircraft carriers being ordered. The committee warned (para 309, 1966):

> If an aircraft carrier were to be ordered, it would have to be the subject of special arrangements ... We do not believe that it is in the best long-term interest of the industry as a whole for the possibility of such an order to be a factor influencing the industry's organisation.

This warning, that the 1960s aircraft carrier ought to be procured by special arrangements, seems not to have been heeded 40 years later as proposals for the future structure of the industry have been determined by the need to procure the CVF with other considerations subsumed. There are, however, two possible explanations for the MoD wishing to create a monopoly besides the advantages it would bring to the CVF project. The first is the MoD has a long-stated policy of not interfering in the defence industrial structure and if, as currently proposed, it manages its demand to create a more continuous even-sized stream of orders then the creation of a monopoly leaves industry to restructure itself to meet the MoD's new procurement strategy. The other explanation follows the first by viewing it as an expansion of partnering into strategic alliancing; given that the MoD wishes to pursue its alliancing approach, which implies a closer long-term relationship with industry, if industry consolidates itself then the MoD has one clear partner with which it can collaborate. The MoD's desire for a monopoly suggests it has forgotten its experience with British Shipbuilders (the higher costs) and also the more recent experience of procuring the LPDs (where the MoD lacked negotiating power as it was dealing with a monopoly).

The role of physical integrator, a firm responsible for overseeing the project, was won by KBR, a subsidiary of Haliburton KBR. Although there was an expectation that KBR would prefer to assemble the ships at its Nigg yard, which is used primarily for oil platforms, this would have caused problems for the Chancellor whose constituency is next to Babcock's Rosyth shipyard whilst a further political concern was the firm's connections to the US government. Neither BAe Systems nor Vosper Thornycroft bid for the position. It is interesting to note

that KBR bid to become the physical integrator and share in the project risk when it has little control of the production itself.

In December 2005 the MoD published the Defence Industrial Strategy, a follow-up to the Defence Industrial Policy. Whilst the philosophy behind procurement remained unaltered – fewer platforms but increased incremental procurement, more partnerships between the MoD and industry, and greater acceptance of domestic monopolies but continuing the MoD's reluctance to intervene in the industrial restructuring – the application to shipbuilding led to new policies. The aim of the document was to specify which areas of the defence base had strategic importance (and therefore gain support from the state to ensure sufficient investment from the global defence industry) and which would be left to the market. The UK's shipyards were not classified as being of sufficient strategic importance; the hulls of less complex and follow-on vessels could be built overseas as the skills involved were not necessary for the UK's defence, rather the design skills and ability to manufacture and integrate the systems for the FOC were what mattered and needed to be maintained. The document admits "procurement strategies and commercial arrangements have not adequately incentivised or enabled rationalisation and efficiency improvements" (para B2.47, MoD, 2005) but goes on to state "we will not micromanage industry's restructuring but it must be customer focused" (para B2.51, MoD, 2005). In essence the MoD aims to give a minimum level of orders to certain firms in order to maintain the FOC skills but will not maintain capacity beyond this. However the reluctance to intervene in the industry means the inefficiencies, which the privatisation of British Shipbuilders was supposed to solve, are likely to remain in the future as all competition for the core workload will disappear. Yet again, despite acknowledging historic failings, the MoD is refusing to intervene in the industry so that its interests can be protected, rather it will merely state an objective and hop industry responds. Given the focus on the core future competition will be reduced. Despite not intervening in the market to ensure future competition, the MoD's position after the privatisation of British Shipbuilders was protected by the misclassification of yards and the end of the Cold War. However as the number of

orders is expected to increase, combined with little prospect of new firms entering the market, the MoD is unlikely to be able to protect its position and will lose further negotiating power which cannot be compensated for through the use of alliances or partnerships.

The implication of this was announced the day before the strategy was published. In a statement about the CVF programme the MoD gave more details about the alliance and how the ships were to be constructed. The alliance between the MoD, BAe Systems, Thales and KBR was joined by Vosper Thornycroft and Babcock (the owners of Rosyth). Vosper Thornycroft was allocated the building work for block 2, BAe's Barrow block 3, BAe's Govan block 4 and Rosyth was allocated block 1 and final assembly. Together these blocks account for 60% of the total project. The remaining 40% was to be allocated by competition to other yards and firms beyond shipbuilding. The omission of Swan Hunter from the alliance suggested the government was starting to narrow its focus onto the yards it considers to have a future and want to work together – Vosper Thornycroft and BAe's yards – and that allocating work to Swan Hunter would just increase overheads and perpetuate the over capacity without any benefit for the future programme. The implication of the statement means there will only be two domestic shipyards able to fulfill the MoD's forward naval programme. Although foreign build is now a possibility the likelihood of it occurring is small given the likely domestic reaction, suggesting the MoD will face a duopoly or monopoly going forward. Whether the lack of competition present in the future will be detrimental to the MoD obtaining value for money remains to be seen. However the MoD got to this situation due to it not being prepared to intervene in the industry and obtain a structure that would protect its interests. It never paid sufficient attention to where competition for its future programme would come from.

4.6 Competition and price

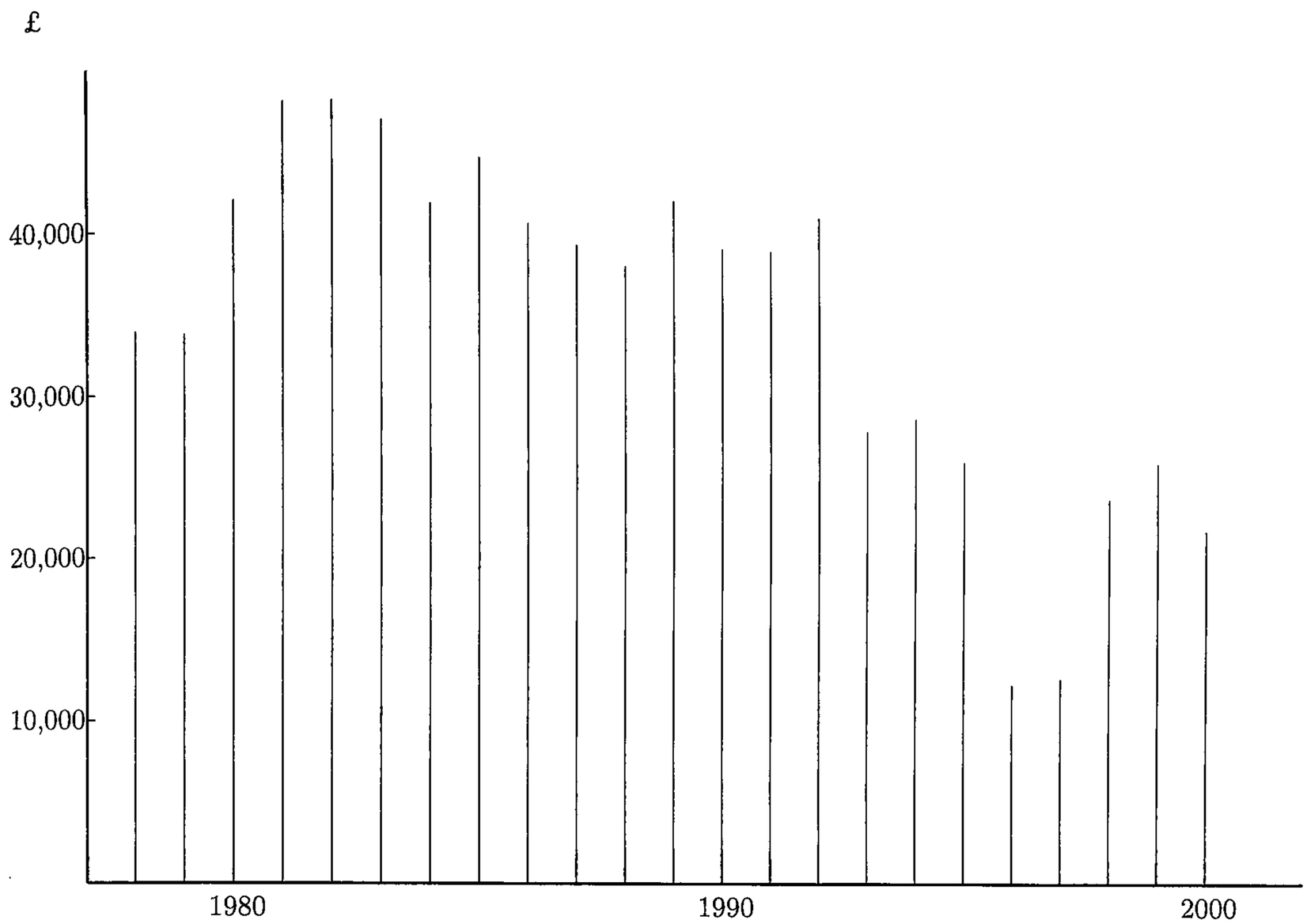
The preceding sections argue that until recently the MoD maintained a blasé attitude towards future competition with the result the number of warship yards has reduced to a duopoly. The effect that this should have on prices charged to the MoD is unclear. Economics suggests

that as the number of firms decreases the price should increase as each firm gains more power reducing the alternatives available to, ergo the power of, the MoD. However the more shipyards there are, for a given procurement programme, the fewer ships are produced in each yard leading to increased overhead costs raising the overall contract price. Furthermore with the size of the Royal Navy decreasing (reducing the potential size of future procurement programmes) firms could be engaging in a longer term view and pricing low now knowing their market power will increase over time as excess capacity leaves the industry. The argument put forward by the MoD states there has been no loss of future competition as firms leaving the industry have only taken away excess capacity. Thus the reduction in the number of yards has been beneficial on the prices paid for ships. Therefore the question arises as to whether there is any evidence to support this claim.

One way to test whether the reduction in the number of shipyards has affected the price of contracts is to look at the bids themselves from the various companies for the different projects offered by the MoD. A panel can be constructed detailing the bid price, project specific factors (eg the size of the vessel), firm specific factors (eg the amount of work the firm already had) and common factors (eg the price of steel), along with measures based on the number of firms. A fixed effects model can then be run to see if the number of firms remaining in the industry influences the bids of the firms. The problem with this methodology is the government does not release details of bids it receives for contracts; the data is unavailable. The government does however provide aggregate data stating how much it has spent on ship hulls every year. Using this time series could cause problems. As the amount spent on ship hulls in any one year is determined by contracts signed during that year or years prior to it the regressors should be lagged but as projects overlap and their associated contracts were signed in different years determining appropriate lags is problematic. Another problem is that it is unclear what proportion of the total amount spent can be allocated to any individual project which restricts the use of project specific variables. Despite these problems it is the best data available to be tested.

The amount spent on ship hulls and machinery, a subcategory of sea systems procurement, is listed in the Defence Estimates (up until 1996) and then in Defence Statistics (from 1997 onwards). As the MoD procures different numbers and different types of vessels each year the most appropriate way to compare them is by using gross tonnage. Even though the order and delivery dates for a ship are on record along with the size of a vessel the problem of allocating how much work was done on a vessel in any particular year remains. After the order has been placed and the contract signed shipyards do not start the work immediately rather they finalise plans and prepare before the first steel is cut. For the second to tenth Type 23s this gap was on average 11 months, varying from 5 to 20 months (calculated from data on page 49, DC, 1990). Even after production has started the work is not uniform – there are peak years of expenditure for a project which detail when the expenditure will be highest but the relative height is not given, neither is a breakdown between the hull and its systems. As these are unknowns the amount of tonnage constructed on a project in a year is estimated to be the total final tonnage divided by the difference between the order date and the delivery date. The total amount constructed in any year is the sum of work on individual projects during that year. Although this uniform approach gives disproportionate weight to the tails on any individual project (the start and end years) it is the only consistent way the tonnage constructed in any year can be calculated. Furthermore as projects overlap through the years the effect should average out. If p_t is the deflated amount spent on hulls in year t whilst x_t is the amount constructed then the dependent variable is the real price of ship hulls per tonne, $\frac{p_t}{x_t}$. Figure 1 shows the real price of ship hulls per tonne between financial years 1978 and 2000. The price increases from 1978, the first year after nationalisation, through to the early 1980s as contracts were signed with a monopoly which forbade its firms from competing in profit. Although the price did decrease in the late 1980s (after privatisation) the price only dropped substantially a few years after the end of the Cold War (in 1993, which also conincided with the LPH contract). The price has remained roughly constant since then, apart from 1996 and 1997 when the MoD ordered the LPDs just before the end of the 1996 financial year (hence

Figure 4.1: Real price of ship hulls per tonne



there is an increase in x without many payments attached).

Anton and Yao (1990) survey empirical investigations into the role of competition in defence procurement. The studies examine the introduction of competition in production after the design and initial production stage which, in essence, equates to whether the government should sole or dual source. Whilst competition brings downwards pressure on prices it does so at the up front costs of establishing competition, both physical, technology transfer and the initial units on steep learning curves. All the investigations are into the learning curve and how the slope changes dependent on whether there is competition or not. The equation estimated is $c = ax^b$ where c is the cost for unit x given $x-1$ units have already been produced, a the cost of the first unit and b the slope of the learning curve. The prices obtained under competition are compared to the estimated prices under the initial sole source and the savings calculated. All of the procurement projects studied are in the fields of missiles, bombs and electronics. As Anton and Yao point out there are some problems with this technique, for example the price not being decomposed into fixed and variable costs, too few observations

restricting the number of explanatory variables that can be used, sample selection problems and lack of strategic pricing in the model. Furthermore the model tests whether the price would have been lower by continuing with the sole source rather than introducing competition from a second source. Even if the data was available it would not be an appropriate model to test as the aim of this chapter is to test whether the reduction in the number of shipyards has had any effect on the price charged to the MoD, not where to introduce competition in the procurement cycle as this, in some form or other, occurs at all stages (either directly or through NAPNOC.)

Johnman and Murphy (2002) demonstrate that shipyards in the UK historically underinvested in capital projects – although they would reduce costs when business was good they still had to be financed when business was bad, unlike labour which could be made unemployed. Consequently owners of shipyards had no incentive to invest when the yards with the most modern equipment were the first to experience difficulty when the downturn returned to the shipbuilding industry. From an economics viewpoint this means a static cost minimisation approach is not an appropriate way to model the cost component of prices. Unfortunately it seems there is no appropriate model which covers all the time periods due to the unique features of the shipbuilding industry. Accordingly there is no theoretic model, rather the relationships are constructed in a more informal manner.

It is assumed the firms in the industry have symmetric cost structures so if each firm has fixed real overheads of k then if n_t firms are in the industry total fixed costs charged to the government are kn_t. As such the fixed costs per tonne, $\frac{kn_t}{x_t}$, captures the effect the number of firms has on overheads and that any reduction in the number of firms ought to reduce the cost to government. Let the period a contract is signed in be denoted τ (where $\tau \leq t$) and $x_{t,\tau}$ the quantity produced in period t that was ordered in period τ. The number of firms can also, conceivably, have an effect on the level of profit per tonne made by firms, $\pi_t(n_\tau)$. The level of profit is determined by competition at the start of the project with the same rate being paid throughout and therefore it is the number of firms present when the project

began that is important. However this gives rise to the complication that in any period t the appropriate number of firms can take different values. This is resolved by using proportions of the tonnage produced during year t that started when there was one firm present, two firms present etcetera. If the years in which the number of firms changes are τ_i where $i = 0, \ldots, j$ then the variables used are $\sum_{\tau_i}^{\tau_{i+1}} \frac{x_{t,\tau}}{x_t}$ for $i = 0, \ldots, j-1$. Thus if the number of firms in the industry changes only once then the profit component in the price per tonne before the price change is represented by $\pi_t = \alpha_1$ and after the number of firms has changed by $\pi_t = \alpha_1 \sum_{\tau_0}^{\tau_1} \frac{x_{t,\tau}}{x_t} + \alpha_2 \sum_{\tau_1}^{\tau_2} \frac{x_{t,\tau}}{x_t}$ (where α_1 and α_2 are constants for a specific number of firms.) As overheads are being estimated by another variable this should capture the effect a reduced number of firms has on profits. As basic economics suggests the level of profit per tonne would be decreasing in the number of firms the coefficients should be increasing in magnitude as the number of firms reduces. The question of which is the appropriate number of shipyards to use remains.

Intuitively it is clear that the appropriate number of yards for determining overheads is different to the appropriate number of yards for determining profits as the former includes all yards supported by government whereas the latter requires the number of independent yards in operation. For example when British Shipbuilders had the monopoly the rate of profit could not be the subject of competition although the government had to pay the overheads of all the yards undertaking its work. Even with this distinction the more fundamental question remains as to what extent the government funded the overheads and which yards provided competition. The answer to the former is assumed to be that the government funds all the warship yards overheads. As described previously the focus of the shipyards has increasingly being on warship orders due to their inability to compete in the merchant shipbuilding sector whilst the level of warship exports during the period was an average of only £85.3m. Given the business strategies pursued by the yards their overheads have to be recovered from the MoD in one way or another. The answer to the second question is not clear either. In different sectors there were different levels of competition; whilst a monopoly existed for nuclear submarines

three firms competed for FOC frigate work whilst most were able to undertake follow-on orders. Thus for individual projects it is possible to identify the competitors, see table 4.4 in the MMC report (1995a), however it is difficult to construct a time series from this. It is also difficult to determine the extent of competition the firms were able to provide anyway. Whilst Hall Russell and Brooke Marine could never be effective competition for the larger yards there was also difficulties for the larger yards competing with one another due to their movements along the learning curve for specific projects and competing firms having to judge what corresponding adjustments to make.

Taking these considerations into account the number of firms for overheads is taken to be the total number of yards whilst for profits it is the number of independent yards with three different groupings of yards being used. All warship yards consists of the seven yards privatised in the mid 1980s (YSL, VSEL, VT, SH, CL, BM and HR); effective warship yards consists of the larger yards (YSL, VSEL, VT, SH and CL) whilst pure warship yards consists of the FOC capable yards (YSL, VSEL and VT). In addition the overheads of Govan were included after it was acquired by BAe Systems. For any year the maximum number of yards was used, so if a yard closed during the course of the year it would be included in that years figures. Although ships for the MoD have been built at Appledore and Harland and Wolff these shipyards have not been included as they have never been dependent on MoD orders and therefore their overheads have never been fully charged to the MoD. Additionally Harland and Wolff have only provided true competition once (for the AOR1) which, due to problems encountered in fulfilling the contract, confirmed their status as a merchant shipbuilder. Scott Lithgow is excluded as their experience in the offshore sector prior to privatisation effectively put them out of the warship building sector despite their attempts to reenter it.

This means the equation to be estimated is

$$\frac{p_t}{x_t} = \alpha + k\frac{n_t}{x_t} + \beta_i \sum_{\tau_i}^{\tau_{i+1}} \frac{x_{t,\tau}}{x_t} + \gamma' Z_t + \epsilon_t \tag{4.1}$$

for all $i = 0, \ldots, j-1$ where ϵ_t is the error term and Z_t a vector of other explanatory variables. These other explanatory variables are given in table 4.2 but include exports, the amount of

Table 4.2: Descriptive statistics

	Mean	Standard deviation	Minimum	Maximum
Pure warship yards overheads	129.3	27.8	97.2	214.9
Effective warship yards overheads	187.0	36.9	97.2	237.0
All warship yards overheads	224.0	66.2	97.2	331.8
Percentage started pre 1978	31.6	36.5	0.0	100.0
Percentage started by British Shipbuilders	11.0	23.8	0.0	82.8
Total tonnage produced in the year	27011	5942	17015	38970
Total tonnage remaining	76796	24630	46680	139225
Index of real steel price	134.3	21.6	97.4	184.2
Real weekly pay	348.1	31.0	302.4	409.8
Base interest rate	9.8	3.5	5.5	17
Real value of warship exports	85.3	103.5	0.0	318.6
Percentage first of class	26.8	14.9	6.5	50.3
Percentage first third of class	28.6	14.0	0.0	47.7
Percentage second third of class	23.2	14.4	2.2	49.1
Real warship hull costs per tonne	34816	10519	12402	48297

work in yards, the percentage of FOCs, the price of iron and steel, interest rates for capital costs and weekly wages. A Wu Hausman test was conducted to check if the overheads measure was endogenous as the number of firms present can be just as much a function of price as price is of the the number of firms. As this suggested the overheads were endogenous the regressions were run using two stage least squares.

The years tested were the financial years 1978/79 to 2000/01 as 1978/79 was the first full year under British Shipbuilders and 2000/01 is the last year data is available for. Descriptive statistics are given in table 4.2. The data for expenditure on warship hulls, exports and the dates used to calculate construction times were taken from the Statement on Defence Estimates (up to 1996) and then Defence Statistics (after 1996). Details on tonnage were taken from the Royal Navy's website and, for older ships, from references in Hansard. The index of iron and steel prices came from Eurostat Iron and Steel Statistics, base interest rates from the Halifax website and weekly pay (including overtime) from the New Earnings Survey for a full time manual male employed in the building and repairing of ships sector. Price variables have been made real by deflating by GDP.

Table 4.3 gives the results when no other explanatory variables are used apart from over-

Table 4.3: Determinants of warship costs per tonne

	Pure	Effective	Effective	Effective	All	All
Constant	-3378.8	-7349.7	-6918.7	-6231.2	-4797.8	-2638.4
	(0.31)	(1.11)	(0.82)	(0.82)	(0.79)	(0.19)
Overheads	107.5*	149.3***	153.2***	162.7***	134.4***	136.7***
	(1.86)	(3.77)	(4.44)	(4.33)	(4.24)	(4.15)
Pre nationalisation	254.7***	164.6***	153.8	132.5**	77.1*	50.6
	(3.26)	(4.31)	(1.49)	(2.52)	(1.86)	(0.34)
British Shipbuilders	366.9***	207.0***	194.0*	164.8***	93.7*	64.4
	(6.86)	(5.64)	(1.77)	(3.34)	(1.79)	(0.40)
7 yards					54.3	29.8
					(0.97)	(0.21)
6 yards					881.1***	864.4**
					(2.98)	(2.69)
5 yards		158.3***	146.3	127.5***	158.4**	123.8
		(5.47)	(1.35)	(3.02)	(2.60)	(0.61)
4 yards			-13.5			-29.6
			(0.11)			(0.18)
3 yards	228.4***			-106.2		
	(3.93)			(0.93)		
R^2	0.7475	0.8993	0.8973	0.8965	0.9127	0.9117

Figures in brackets show the robust t-statistics. *** denotes significance at the 1% level, ** at the 5% level and * at the 10% level. The R^2 coefficient is for generalised R^2.

heads and the number of firms in the industry. The number of firms includes production awarded before the industry was nationalised, during the warship part of British Shipbuilders existence and post privatisation with the smallest post privatisation number being excluded for the profit element. All three configurations of warship yards are included. Column 1 reports the regression when the pure warship yards was used (the three core FOC yards). Columns 2 to 4 uses the enlarged group of effective warship yards in three different combinations. In column 2 Cammell Laird is included only until the time of its first receivership whilst column 3 includes its return after receivership. Column 4 includes Cammell Laird only once but delays Swan Hunter for three years as it took time to convince the MoD the yard was sufficiently financially secure to be awarded a contract. Columns 5 and 6 include all the

warship yards; in 5 Cammell Laird has been included only once whilst 6 includes it twice. The testable implications of the arguments put forward by the MoD are the measure for overheads should be statistically significant with a positive sign, so that as the number of firms decreases the price also decreases for a given tonnage. Secondly the effect of the number of warship yards after privatisation should be statistically of the same value as the number of yards has affected only the amount of overheads levied on the MoD and has had no affect on the competition for contracts (if the reduced number of competing yards has not given them the ability to price higher). On the former assertion the level of overheads is statistically significant suggesting the MoD has benefitted from having to support fewer yards. On the latter the answer is not so clear. The typical story is the coefficient per percentage point of tonnage increased after the creation of British Shipbuilders but reduced after privatisation to a level below that obtained in the pre British Shipbuilders era. However under all warship yards there is a statistical increase after privatisation. This result, though, occurs due to Hall Russell and Brooke Marine essentially acting as year specific variables (the proportion of ships ordered in one year) rather than a reflection of the number of yards. For the other groupings of yards there does appear to have been a reduction in profit after privatisation. Furthermore as the number of yards reduce the coefficients tend to decrease (or become statistically insignificant) rather than increase, given the increase in power gained. This can be explained by the decrease in orders in the 1990s and the need for firms to win contracts in order to survive; although each remaining firm had more pricing power the lack of orders from the MoD meant the firms were unable to exploit their power. Therefore the MoD gained not only from reduced overheads but also from the increased competition for the reduced number of orders – the MoD exercised its power through not acting and withholding contracts from competition. An alternative explanation is the MoD were able to restrict rents when competition was low or absent; however this explanation counters the evidence suggesting the ferocity of competition in the 1990s (for example the LPH) and the NAO report on NAPNOC (NAO, 2001.) It also counters evidence Vosper Thornycroft gave to a Parliamentary inquiry into shipbuilding that

warship contracts were increasingly difficult to obtain and consequently only lower financial returns could be earned (67, SCEC, 1998). The CDP stated that the MoD held the power as it also held the money (Q15, PAC, 2002) though this suggests not spending the money was more powerful. However it has to be remembered that industry still retained power as the MoD never fully enforced contracts that were unfavourable to industry as it would jeopardise their other projects (Q42, DC, 2004).

Table 4.4 gives the results when explanatory variables are included. For all columns the effective warship group is used with Cammell Laird being included only once. Column 1 repeats column 2 of table 1 in order for comparisons to be made. Column 2 gives the results when variables to represent the learning curve are introduced. The learning curve states that the more that has been produced, the less each subsequent unit should cost. The variables tested are the percentage of tonnage produced in a year that are first of class, in the next third of class and in the middle third of the class. If a class consists of fewer than four vessels the first is the FOC, the second comes in the first third and the third in the second third. Although this groups vessels which are different numbers it would be expected that the later ships in the class should be associated with a lower price than earlier ships in the class. This, however, is not borne out by the regression which suggests there is no statistically significant learning curve effect on prices. Since this disagrees with the arguments used by the MoD two further measures of the learning curve were used. The first was to use the proportion of ships by tonnage that were first of class, second of class, third of class and so on. This increased the number of exogenous variables considerably in relation to there being only 23 observations and none of the coefficients was statistically significant. In order to gain more degrees of freedom the final measure used was a specific learning curve where if the ships were ranked by class so the FOC would be $r = 1$ then the cost of the vessel should be ar^b where a is the notional first of class cost and b the learning curve coefficient. Accordingly for a given period t the variable used was the position on the learning curve, with predetermined slopes, weighted by tonnage or $\sum_r \frac{x_{t,r}}{x_t} r^c$ for each period t. The values chosen for b were -0.05, -0.10, -0.15 and -0.20. All

were statistically insignificant. Throughout overheads and industry structure measures were significant. There are three possible reasons why no learning curve is present in the data contrary to the arguments of the MoD. The first is that each individual project is subject to its own learning curve slope and not a common slope, which is what the methodology assumes. The second explanation is the savings in price were not due to the learning curve but by the need to submit lower bids in a period when the sector was contracting in order to have the possibility of remaining in business. The third explanation for the absence of the learning curve is that learning by doing is inhibited by the short production run (the largest class included is the Type 23 which consisted of 16 vessels) spread over a large number of years (financial years 1984/85 to 2000/01) which allows scope for design evolution further constraining the potential to learn; the last of class is never expected to be the same as the first of class vessel.

Column 3 includes size effects. The expectation would be the greater the loading of the yards the lower the cost would be whilst the more work yards have remaining the lower the cost as firms would have no need to delay projects in order to remain in business or, as documented in Johnman and Murphy (2002), workers working more slowly on the last ship in the yard so they can do overtime before being made redundant when the yard closes. Neither of these propositions are borne out by the date, both are statistically insignificant. Once the overheads have been paid, which are statistically significant, the actual volume of work has no effect on the price; loading affects the price only as far as recouping overheads and does not introduce economies of scale. Also insignificant are the variables in column 4 used to reflect costs incurred by yards: wages, capital costs (base interest rates) and raw materials (an index of iron and steel prices). As the variables used are contemporaneous it is assumed that yards' expectations of their costs are accurate. However these representative costs faced by the yards do not explain the prices paid by the MoD. Column 5 includes what has been said repeatedly to be the savior of the sector: exports. Exports are assumed to benefit the price paid by the government in two ways. The first is that it helps to recoup overheads and

thus lowers the proportion charged to the MoD and secondly it employs a yard even when there is no MoD work ensuring it is able to compete in the next MoD competition and bring further competitive pressures to the price finally charged. The lack of statistical significance for exports suggests that it brings no direct benefit to the MoD in terms of the price it has to pay for its domestic warships. Exports lack of effect on prices could be due either to the level of exports never being sufficiently large to sustain yards in the absence of MoD orders or yards viewing the winning of exports as being unlikely and therefore not factoring them into prices when competing for MoD contracts. The final column, 6, includes a variety of these measures to see what effect they can have in combination. The only variables which remain statistically significant are the measure for overheads and some for the industrial structure.

The statistical significance of the overhead measure and the industrial structure measures remain when the regression included a time-trend (not reported). The time trend could have, for example, represented an increase in the cost of technology over time. This empirical analysis supports the preceding arguments in three ways. Firstly the significance of the overhead measure supports the MoD argument that it has benefitted from a reduced number of firms as it has not had to pay for under loaded firms. Secondly the coefficients for the industrial structure also support the MoD's view that privatisation decreased costs – for a given proportion of tonnage the cost increased after nationalisation but reduced to a lower level after privatisation. Thirdly the contention that the MoD's unfettered pursuit of competition has not brought about any adverse consequences in terms of ship hull prices appears to be borne out by the data. However the fact that the price decreases with the number of yards, as shown in table 4.3, suggests this is due less to the MoD's industrial policy (where the benefits of reduced overheads should be compared to the increased profit paid to the remaining firms) and more to the lack of orders in the 1990s and firms bidding for contracts just to survive. The data tested here finishes in financial year 2000 and therefore finishes just as the number of naval orders is increasing (Type 45s, CVFs and the Future Surface Combatants). It will be interesting to see in the future whether the remaining firms will be able to exploit their

power, and thus negate the benefits of reduced overheads, or whether the optimal number of firms remain (whereby the overheads equal the marginal increase in costs due to the reduced number of firms).

4.7 Conclusion

The privatisation of the naval shipyards in the mid 1980s furthered the MoD's aim to introduce competition into defence procurement as it transferred hull production away from a domestic monopoly to a domestic oligopoly. This alteration to the industrial structure enabled the MoD to have competition for hull construction contracts and meant it was prepared, for the most part, to leave any industrial questions to the market with market forces determining the industrial structure. After 1985/86 contracts were awarded solely on the criteria of value for money; at first this was just defined by price but later expanded to include quality, time and life-costs. The industrial restructuring consequences of the distribution of contracts was never a prominent factor with the MoD making no effort to create and maintain an industrial structure able to deliver value for money in the long term. Even the resolution of the Cold War was not sufficient reason for the MoD to alter its procurement policy. Despite the decline in orders at the start of the 1990s the MoD continued to maintain it was for industry to restructure itself whilst the MoD would contract with what remained.

The ships procured during the 1980s and 1990s demonstrate not only the preeminence of the short term, for example the LPH contract, but also a disregard as to how future competition could be achieved. The LPDs showed that if there was no competition for a vessel the MoD would have even less bargaining power and be reliant on offering a sufficiently attractive package (in terms of price, risk, time and quality) to the shipyard to build it, not the other way round that would be expected in a normal buyer-seller relationship. However there was never any realistic prospect of bringing competitive forces to bear unless there was another firm competing for the contract. The AORs showed the difficulties in non-naval shipyards constructing naval ships whilst the other accountancy based routes (for example

post contract auditing or pre contract benchmarking) have not been successful for the MoD historically. Finally given the political, as well as defence, consequences of the hull being built abroad the rational response should have been for the MoD to intervene and ensure the market maintained sufficient competition, rather than rely on the market to maintain the competition itself. However the MoD's unflinching support of the market meant the future industrial structure, and the problems of dealing with a monopoly, was never given much attention.

The fierce competition for contracts led to some firms leaving the industry whilst those that remained faced difficulties throughout the 1990s. The empirics suggest the MoD's assurances that the loss of yards was beneficial due to the reduced overheads charged to it have proved valid. However the lack of power brought to bear by the firms as the sector consolidated suggests the MoD was able to retain power after privatisation; at first this was due to the excess capacity after privatisation and subsequently by the MoD not procuring vessels after the Cold War ended. This meant the remaining firms had to submit ever keener prices in order to survive and thus were unable to use their increased pricing power. Therefore with an increase in the naval procurement programme it will be interesting to see if sufficient firms remain to protect the MoD's financial, and other, interests or whether the lack of attention given to future competition will result in higher costs for the procurement programme.

However the problems that were encountered on the Type 45s and, more recently, the CVFs have led the MoD to question their commitment to competition as a procurement mechanism. The lack of an immediate response to BAe Systems' offer to be the sole builder of the Type 45s shows the lack of a naval policy (in terms of procurement and industrial structure.) That they required RAND to undertake a study into this and procurement issues relating to the CVF suggests that the MoD had, and has, no naval procurement policy at all, rather it has subcontracted policy making to RAND. At least the BAe Systems proposal for the Type 45s led the MoD to consider future competition and this has subsequently been reinforced by the Defence Industrial Policy and the Defence Industrial Strategy.

The most recent proposal from the MoD is for the remaining industry to group together and restructure itself without MoD involvement. The MoD will then work in partnership with the remaining industry. However a partnership with industry can only work if both parties are working to achieve the same objective and can trust one another to achieve it. Further it also requires the industry to restructure itself. It is difficult to see this mechanism being effective; not only is there a lack of trust between industry and the government there is also a lack of trust amongst the firms preventing restructuring (combined with commercial considerations, for example pricing assets). The MoD refuses to accept its role as the principal purchaser of goods from the industry and to ensure it restructures in a way that protects the MoD interests. The MoD's procrastination and reluctance in becoming involved in the industrial base needs to end otherwise what remains of the industry will configure to the MoD's detriment. The next chapter proposes an alternate procurement mechanism, namely directed buys. This system should ensure that the power can return to the MoD and that their interests can be protected. However it also requires the MoD to accept its responsibility with regards to the industrial base and decide how many firms should remain.

Table 4.4: Determinants of warship costs per tonne

	1	2	3	4	5	6
Constant	-7349.7	-3676.1	-4862.2	-26924.9	-8963.9	-35269.6
	(1.11)	(0.22)	(0.32)	(0.72)	(1.17)	(0.75)
Overheads	149.3***	153.3***	152.3***	145.8***	158.1***	141.4***
	(3.77)	(3.65)	(3.32)	(3.35)	(3.85)	(3.12)
Pre nationalisation	164.6***	151.2**	207.9***	224.5	162.1***	243.3
	(4.31)	(2.29)	(3.10)	(1.32)	(3.80)	(1.25)
British Shipbuilders	207.0***	186.4**	228.6***	248.2**	203.3***	279.2*
	(5.64)	(2.40)	(4.76)	(2.51)	(5.77)	(2.04)
5 yards	158.3***	150.0***	182.6***	176.9***	157.3***	184.7**
	(5.47)	(3.75)	(4.24)	(2.94)	(5.22)	(2.61)
First of class		-92.5				-86.5
		(0.40)				(0.37)
First third of class		12.2				99.3
		(0.09)				(0.63)
Second third of class		-51.0				58.4
		(0.30)				(0.31)
Total tonnage produced			-0.39			
			(0.70)			
Total tonnage remaining			0.06			
			(0.90)			
Steel price				-72.0		-155.8
				(0.38)		(0.66)
Wages				62.2		104.1
				(0.84)		(1.16)
Interest rates				569.8		663.4
				(1.41)		(1.18)
Exports					1.8	18.4
					(0.17)	(1.17)
R^2	0.8993	0.9022	0.9028	0.9142	0.8946	0.9298

The figures in brackets show the robust t-statistics. *** denotes significance at the 1% level, ** at the 5% level and * at the 10% level. The R^2 coefficient is for generalised R^2.

Chapter 5

An alternative procurement mechanism for the future

Defence spending in the United Kingdom has declined from around five percent in the mid 1980s to around two and a half percent currently. Running parallel to this decrease is the increase in the use of competition in awarding defence contracts. In 1979/80 14% of contracts placed (both by number and by value) were as a result of competition; by 2001/02 they accounted for 35% of contracts by number but 61% by value (DASA, 2003). Smith (1990) points out the increased use of competition in procurement led to more firms receiving contracts. However since the end of the Cold War there has been a wave of consolidation in the defence sector in response to the peace dividend and the associated reduction in national defence budgets. At first there was vertical integration with the prime contractors taking control but the current focus is on horizontal integration at both the prime and subcontractor level. This means in the last decade there has been a reduction in the number of independent firms able to compete for MoD contracts.

Economic theory suggests competition for procurement contracts is desirable as it should ensure an efficient allocation of resources. The theory continues by suggesting suppliers of a good have to adapt to the prevailing market conditions; the consolidation forced by the peace dividend should have reallocated capital and labour more efficiently. If the circumstances change, then the market should readjust with new firms being created if necessary (for example the presence of supernormal profits). However unlike most economic goods there are market entry problems for firms wishing to produce defence goods. The government, typically the sole

Table 5.1: Firms paid over £100m by the Ministry of Defence in 2002/03

Over £500 million	BAE Systems (Operations) Ltd BAE Systems Electronics Ltd	NETMA	QinetiQ Ltd
£250 to £500 m	A W E Management Ltd Defence Science & Technology Laboratory	Devonport Royal Dockyards Ltd General Dynamics Ltd MBDA UK Ltd	Rolls Royce PLC Westland Group
£100 to £250 m	ABRO Alenia Marconi Systems Ltd Annington Receivables Ltd Babcock Support Services Ltd BAE Systems PLC BFS Group Ltd	British Telecommunictions PLC DARA EDS Defence Ltd Fleet Support Ltd Fujitsu Services Ltd IBM United Kingdom Holdings Ltd	Interserve(Defence) Ltd Lockheed Martin Corp Other UK Departments Royal Ordnance PLC Serco Group PLC

Data taken from Table 1.6, Defence Statistics 2003

buyer of output, is only prepared to contract with certain firms for national security reasons. Also the value of a defence firm lies in its designers and engineers who have assimilated human capital throughout their working lives in the sector. A firm establishing a new team with no experience would be viewed by the government as having very little possibility of succeeding and there would be additional concerns over whether the firm possessed the necessary financial security. Consequently a new firm would be unlikely to win any contracts.

This market entry problem means there is a problem if the MoD adopts a laissez faire approach to the defence industrial structure as the industry could be unable to respond. This, though, is not the only reason why a government might desire to take a more active involvement in the shape of the defence industrial base. Other reasons are split between the defence argument (mobilisation base, strategic needs, knowledge spillovers etcetera) and the political argument (national sentiment, technological spillovers and employment). Whilst these suggest the need for a large domestic defence industrial base there are countervailing arguments in favour of a smaller industry, principally the limited funds available to defence from the national budget alongside demands for value for money from each expenditure. The maintenance of defence firms requires the procuring agency to procure from each meaning economies of scale in production can be left unrealised and duplication occurring with repeat costs.

The combined result of these factors is a requirement on the MoD to take an active role in

the defence industrial base. This is not a problem unique to the MoD – the US's Department of Defense (DoD) now reviews proposed consolidations to preserve essential competition for innovation and cost discipline. Kovacic and Smallwood (1994) suggest competition is more necessary for innovation than cost discipline as the US military rely on highly technologically innovative equipment; cost is a secondary concern to performance. Their analysis suggests the DoD ought to be more active in overviewing proposed mergers and acquisitions in order to maintain competition in all areas and at all levels. Latterly the DoD has accepted this argument with the 'Annual Industrial Capabilities Report to Congress 2001' stating the oversight given to any proposed merger has to be greater now than in the past. However it also acknowledges the monopsonistic position of the military as the purchasing decisions it makes can dictate the shape of the market. In July 2000 the DoD changed its procurement practices so that the impact a purchasing decision has on future competition has to be considered. This reinforced the view that competition is vital in the defence sector and should be preserved.

The previous chapter demonstrated the MoD pursued a similar policy response to the DoD in the shipbuilding sector; the market was left to decide its own structure before the MoD decided it had to intervene and consider the effect actions would have on future competition (as stated in the Defence Industrial Policy 2002 and Defence Industrial Strategy 2005). However the laissez faire approach extended to all defence markets, not just shipbuilding, and has meant the MoD has fewer options when it comes to procurement. Table 5.1 shows all the firms receiving contracts over £100 million in 2002/03. Altogether there are 27 firms receiving contracts over £100 million however this suggests a greater degree of competition than is truly present.

BAe Systems is the parent company of BAe Systems (Operations) Ltd, BAe Systems Electronics Ltd and Royal Ordnance PLC (all of which it wholly owns). In addition to this it has various joint ventures on the list. MBDA UK Ltd is owned by BAe Systems (37.5%), EADS (37.5%) and Finmeccanica (25%) whilst BAe Systems (50%) and Finmeccanica (50%) jointly own Alenia Marconi Systems Ltd. Fleet Support Ltd is a joint venture between BAe Systems

(50%) and Vosper Thornycroft (50%) who have three wholly owned subsidiaries receiving lower value contracts (between £25 and £50 million). Payments to NETMA represent payments towards the Typhoon (previously called the Eurofighter). As each partner country in the project receives the value of work roughly in proportion to the proportion of aircraft they are buying these can be viewed as payments towards BAe Systems (for the airframe) and Rolls Royce (for the engines). A W E Management Ltd is an equal joint venture between British Nuclear Fuels, Serco and Lockheed Martin (with the latter two also appearing separately). The Westland Group PLC is part of AugustaWestland, which in turn is equally jointly owned by Finmeccanica and GKN. Devonport Royal Dockyards Ltd is also a joint venture between Halliburtons (51%), Balfour Beatty (24.5%) and the Weir Group (24.5%). Finally the Defence Science and Technology Laboratory, ABRO and DARA are all parts of the Ministry of Defence itself.

Therefore including these ownership structures suggests there is less competition than just the number of firms receiving contracts would suggest. However the structure of firms receiving payments of a lower value also distort the level of competition when their various subsidiaries win contracts separately. An example of this is Thales whose various firms were paid at least £230 during this period yet no single part was paid more than £100m. Although the MoD only releases how much an organisation was paid in bands, for example £50 - 100m, it is possible to estimate how much independent firms, for example BAe Systems or Thales, earned. If the mid point of each band is used combined with splitting payments for joint ventures according to a firm's share in the project, only 3 firms were paid over £500m, 6 firms £250 - 500m and a further 18 firms £100 - 250m.

The argument of this chapter does not concern the oversight of consolidation, as this has already occurred, rather it focuses on how contracts ought to be distributed amongst the remaining firms. It is assumed that only two firms remain with different costs and that the MoD can either continue with competition as usual, with the possibility of a monopoly, or alternatively intervene in the market and distribute the contracts between the two firms so

that there can always be competition between them if needed. The first approach offers short term efficiency whilst the second offers long term efficiency. The question that arises is which offers the greater efficiency overall, short run or long run?

The model is based on a need for the government to intervene in the market and determine the market structure. Given that only two firms remain, it is possible for the lower cost firm to win a monopoly in the first period due to their cost advantage. Therefore if the government wants a second firm to remain in the industry to limit the rents available to the other firm in the second period, the government has to intervene in the market to ensure the higher cost firm has work and can survive. In order to achieve this it has to offer each firm a contract for which the dominant strategy is to accept. In essence this requires the other firm to accept a contract if the former strays from the equilibrium path. The punishment of no work, and consequent closure of the firm, provides sufficient incentive on the equilibrium path for each firm to accept the contract (if they are designed correctly). Thus the government has to design contracts acceptable to both firms if both firms are to survive. This chapter suggests this is possible and that the loss of short term efficiency involved is more than compensated for by the gain in long term efficiency.

Section 1 reviews the existing literature whilst section 2 introduces the basic model. Some extensions are also presented in section 3 with fixed costs introduced in section 4 and capacity constraints in sections 5. Section 6 discusses the allocation of rent before section 7 concludes.

5.1 Existing literature

The literature on procurement in general is vast. However there are distinct areas relevant to this paper, namely relating procurement to the industrial structure, split award contracts and dynamic issues. The literature relating procurement to market structure is small, but there has been particular mention of it in relation to defence.

Kovacic and Smallwood (1994) suggest two ways in which the horizontal integration occurring in the United States military aircraft sector can be controlled by the government. Firstly

the legal system grants the right to the government to approve or reject proposed mergers in an industrial sector. Secondly the government controls the distribution of contracts between the firms and is in a position to determine the optimal market structure accordingly. They assume competition is a desirable feature to be maintained in relevant product markets as it fosters not only design competition but also price competition. Therefore the optimal market structure ought to maintain as many rivalries as possible. Anton and Yao (1990) provide a survey of empirical research into defence procurement. After competition for production has taken place savings are observed in all bar one of the studies. However when start-up costs are excluded savings cannot be guaranteed as a consequence of competition suggesting competition is a measure that ought to be used with caution. The criticisms the authors level at the studies mean forecasting when to employ competition in production is unlikely to be reliable. As such competition will not always ensure lower prices.

There is also some theoretical literature linking procurement to the market structure. The first strand considers whether contracts should be split or not. Anton and Yao (1989) compare split award contracts with winner takes all contracts when the market consists of two firms possessing complete information. Their positive analysis suggests split awards being Pareto optimal from the viewpoint of firms, with each firm earning a profit equal to their efficiency gain relative to the sole source cost of their opponent. Although the firms will coordinate their split where the project costs are lowest, the procuring agent has to pay rents to both firms. As such the power lies with the firms and not with the agent. They extend their analysis (1992) to consider the same problem in the presence of imperfect knowledge. Asymmetric information with regards to costs makes it harder for firms to coordinate their bids so a split award contract can be Pareto improving for both firms and the government in comparison with a sole sourcing contract. Unfortunately their analysis does not extend to providing an optimal purchasing system and views only a static problem; after repetitions each firm will gain knowledge of its competitors costs, lessening the asymmetries and making coordination in split award contracts more likely. Thus returning to the complete information case any aim

of maintaining competition through the use of split award competitions comes at a cost to the procuring agent.

A second strand considers whether a monopoly or duopoly is preferable. Auriol and Laffont (1992) use a Baron-Myerson type model to compare the optimal industry structure dependent upon when the cost characteristics are learnt. A regulator exists whose aim is to maximise a utilitarian social welfare function in the presence of information asymmetries. Their general result is duopoly is preferable when the industrial structure is determined before the costs are known whereas a monopoly is preferable after the costs have been discovered. Under duopoly there is the replication expense of fixed costs, though they identify two ways this is beneficial. The first is the sampling effect; in duopoly there is a higher probability of obtaining a draw of a low cost firm than in monopoly. The yardstick effect, the second, operates by limiting the scope for information rents as the competition allows correlation of efficiency parameters. The final benefit of a duopoly occurs when production costs are convex. If the efficiency parameters are not too different in magnitude then the optimal contract is a split award contract with the split determined according to the marginal costs of production. In comparison McGuire and Riordan (1995) find that single provision of a good is appropriate if the social cost of profit is positive but small. Further, information asymmetries bias the optimal market structure in favour of a single provider as the economies of scale increase. Thus the cost function faced by firms in each industry seem to favour a different optimal market structure.

In Dana and Spier (1994) the government auctions the production right to two firms with the market structure determined by their bids, however the government retains the right to produce if firm costs' are too high (and thus maximise utilitarian welfare). Under complete information any increase in the private sector production costs moves the market structure away from a monopoly towards a duopoly. Under incomplete information a similar increase moves the market structure away from a duopoly towards either a monopoly or government production. As monopoly rights are valuable to the firms they are prepared to bid more in order to win them in order to differentiate themselves from their opponents. Riordan and

Sappington (1987) look at how a monopoly franchise ought to be awarded. An increase in the number of firms bidding has no effect on the overall market price or quantity whist the franchise fee is non-decreasing in the number of bidders. They assume the marginal costs of production are sufficiently high relative to the fixed costs so only one award will be made, even if the firm turns out to be a high cost type.

Jehiel, Moldovanu and Stacchetti (1996) look at how auctions operate when the identity of the buyer of an indivisible object affects the other bidders. This manifests itself as an externality between bidders; if the sum of the externalities associated with any sale is larger than all the valuations associated with it the seller is better off not selling the object at all (though revenue is still received). Also differing from standard auctions is that the seller can obtain surplus from all bidders even if they do not win the object. The application of their paper is how Ukraine and the world should deal with the nuclear weapons they inherited from the Soviet Union, namely the international community should pay Ukraine to dismantle their nuclear weaponary. Although the MoD has to sell the procurement contract any externalities it creates, for example a monopoly, needs to be considered.

There are some papers which consider how a project should be procured when it is necessary for information to be ascertained before production takes place. Rob (1986) looks at how learning buys can affect the optimal procurement contract. Firms are able to make draws from a cost function with full memory at a fixed cost but the technology associated with any draw is partially transferable between firms. The government faces the choice of how to split the contract to procure a given quantity. The advantages of possible lower draws (through increased investment by firms knowing they will produce more of the good) has to be balanced against the advantages of a larger proportion being awarded competitively with less uncertainty. With a small number of bidders it is more likely a time sequential split award contract will be awarded to lessen monopoly rents. The split here is to lower production costs for one project and not a series of projects (similar to the RAND analysis of the Type 45). Anton and Yao (1987) investigate how learning by doing affects second sourcing contracts.

They assume the government needs to procure a fixed quantity. Initially they procure some of the good from a developer with the remainder being auctioned through a sealed bid auction (after information regarding costs has been ascertained); if an auction is not feasible an old system can be purchased for a known price. The government, in determining what proportion to offer for initial development and what contracts to offer, has to trade-off the benefits of more competitive bidding in the auction against truthful revelation by the developer. As such it might be more profitable for a developer to misrepresent initial costs knowing they will not subsequently gain the opportunity to bid for the remainder of the production. This can be overcome through the use of a cut-off mechanism; when reported development costs are sufficiently low a sealed bid auction is held for the remaining production whilst if high costs are reported the old system is purchased. However the threat of the cut-off has to be credible if it is to work.

These two papers think about the dynamics of a single project whereas all the papers before it are concerned with a single, static project. However as mentioned by Kovacic and Smallwood (1994) the government can determine the market for many periods ahead through their actions in any one period. Consequently if a single source contract is entered into one period then there might not be another firm present in the next period for dual sourcing to be possible. This can result not only in increased prices charged to the government but also in increased production costs for the firms. The final group of papers considers the dynamics of procurement. Luton and McAfee (1986) assume there are two projects to be auctioned in two periods. At the start of each period the firms obtain a cost draw from a common distribution, in period 2 each firm's cost is its lowest draw. The winner of the first auction has an advantage going into the second as it knows it was the lowest cost producer in the first period. As such it is optimal for the government to discriminate between against the incumbent firm in order to minimise total government expenditure: the rival wins in the second period if it beats the first period price of the incumbent. Therefore it is possible the high cost firm will produce in the second period (though this is balanced against the first firm having to bid more aggressively in

the second period). Their analysis assumes the number of bidders is the same in both periods.

Lewis and Yildirim (2002) model how to manage dynamic competition where there is learning by doing. They assume the presence of two firms each facing the same cost structure: $c(x_i, c_i) = c(x_i) + c_i$ where x_i represents how much firm i has previously produced and c_i is an idiosyncratic error (drawn from a common distribution and changing each period) – there are no fixed costs. The paper proves the existence of a Markov perfect equilibrium. The government making the procuring decision has to choose at what speed to realise the learning by doing effect. As δ approaches one the expected probability that either firm is chosen to produce approaches one half; in the infinite horizon model the gains from learning by doing are bounded below so both firms should eventually reach the horizon meaning in each period the government chooses the firm with the lowest idiosyncratic cost. However as the future becomes relatively less important the opportunity of market tipping (monopoly) occurs. The size of the experience effect determines this; if it is sufficiently large then this offsets the benefits of maintaining competition. However even after tipping has occurred from the assumption regarding no fixed costs they assume the uncompetitive firm remains in the market so as to limit the rent available to its competitor.

The paper of most relevance is Klotz and Chatterjee (1995) as this is premised on actions taken in the first period directly affecting the actions that can be take in the second period. They model two firms competing for two repeated procurement project from the government. The firms costs are composed of random draws from identical cost distributions combined with, in the second period, learning by doing (dependent on the amount produced in the first period.) As there is a fixed cost of entry to the auction for the procurement contract the government guarantees each firm a fixed proportion of the contract so the fixed costs can be recovered before auctioning the remainder of the contract. The government's policy variable is the amount of the contract that should be auctioned – it has to be sufficient for the firms to recover their entry costs but not too large so one firm moves down the learning curve restricting the effectiveness of the second period competition. The paper concludes that

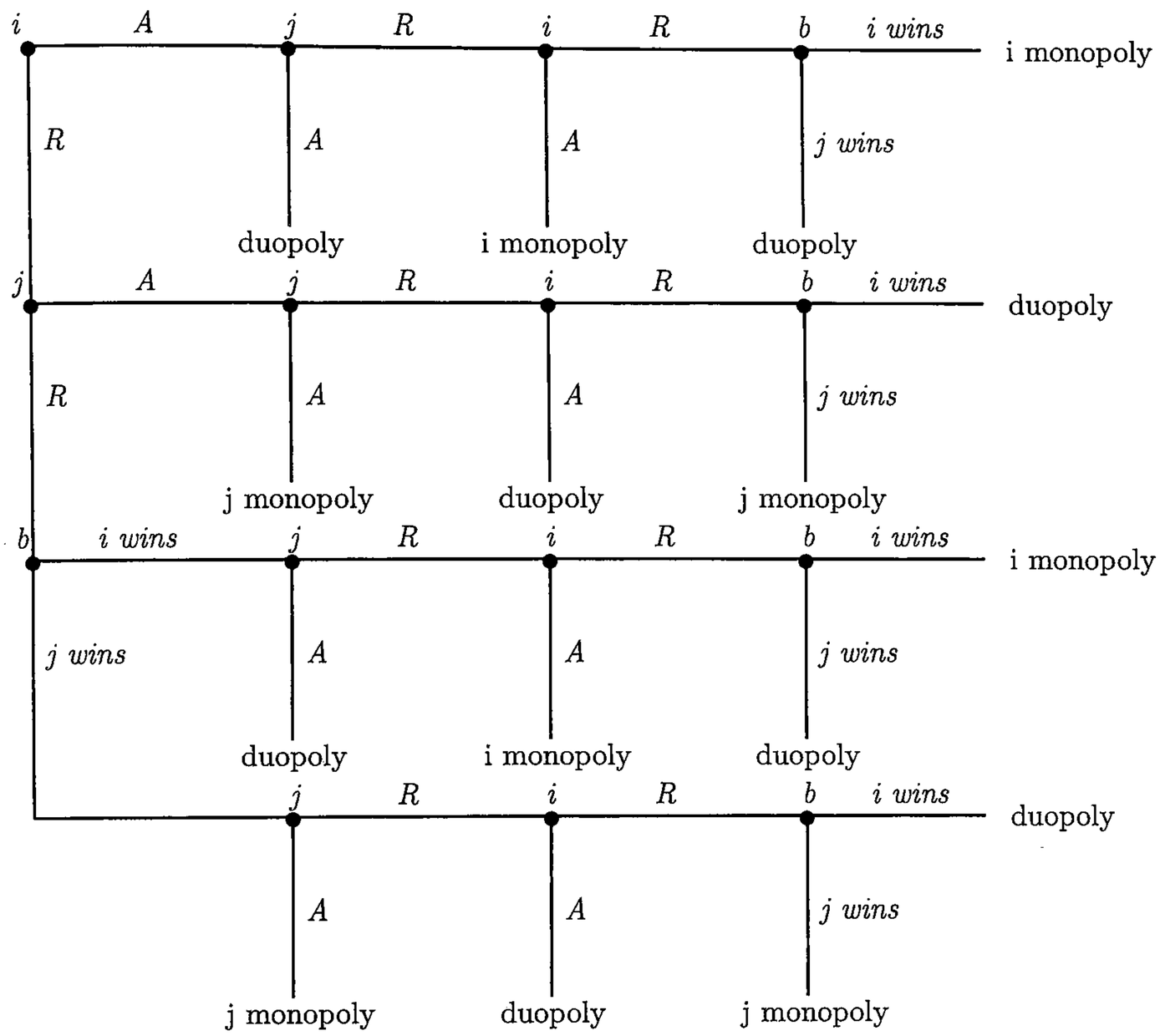
there are benefits to dual sourcing to counteract the problems winner takes all contracts can induce in the first period (for example the movement down the learning curve.) This paper differs from Klotz and Chatterjee by using a different procurement mechanism and assuming non-identical costs for the two firms.

5.2 The model

Assume the government has a project that takes two periods to complete (with the project having the same size in both periods). The government values the completed project at w. This does not necessarily reflect the social valuation of the project as it could, for example, suggest the maximum price the government is willing to pay a domestic firm to undertake the production (and hence w would equal the non-domestic cheapest price plus any associated costs from not procuring nationally). For some reason the firms who undertake the project are unable to commit to their actions in the second period at the start of the first period; the firms might not know what the costs in the second period will be or alternatively the firms might not be willing to enter into long-term agreements so as to retain flexibility in future periods. Equally the problem could be the government is unable to enter into a long-term agreement with firms so as not to bind the hands of its successors or does not know what the second period project will encompass. Due to problems with commitment in the second period it means the government is unable to write a complete contract to cover both periods at the start of the project. At the start of the second period the project has a scrap value of u and a second period completion value of v where $u + v = w$. Furthermore it is assumed the discount factor equals one.

The government is unable to undertake the project itself. There are two firms remaining in the industry. If either firm receives no production contracts in any period then the firm leaves the industry. One possible explanation is with no work to do the skilled employees will leave the company and find employment elsewhere leaving the firm void of skills for future work. It is assumed that firms have constant average and marginal costs of production. It

Figure 5.1: Dual sourcing possibilities



is also assumed that firm one is more efficient than firm two so firm one's costs are α whilst firm two's are β, with $\alpha < \beta$. Furthermore it is assumed that neither firm faces any capacity constraints and that the project itself is perfectly divisible. Finally the government is unable to exploit its position meaning the total price of the contracts offered to a firm over the two periods has to at least equal the costs incurred by the firm.

Figure 5.1 represents the sequence of moves in the first period. At the start of the period the government offers firm i a contract which specifies the split of the contract the government wishes it to produce and the price the government is willing to pay for it. Firm i can either accept (A) or reject (R) the contract. If firm i accepts the contract then firm j is offered its own contract for the remaining proportion of the first period project and the price the government is willing to pay. It too then chooses whether to accept or reject. If it chooses

to accept then both firms produce according to their contracts and the first period ends. If either firm rejects their contract then the contract which they rejected is offered to the other on the same terms (for the same proportion and the same price). They then choose whether to accept or reject. If they both reject the same contract then the government auctions the contract (represented by b in figure 5.1). The government runs the auction by starting with its valuation and decreasing the price until one firm says they will not be willing to produce that proportion of the contract for a price below it. The other firm then wins the auction to produce that proportion at that price. If both firms report the same price then, as a tie-break, the firm with the lowest cost is awarded the contract. This auction avoids a probabilistic and inefficient outcome. As figure 5.1 shows at the end of the first period it is possible for either firm to have a monopoly or for both firms to remain in business.

The sequence of moves in the second period depends on the number of firms remaining in the industry after the first period. If both firms survived then the second period proceeds in the same way as the first provided both firms accepted their first period contracts (as described in the previous paragraph). If one or both firms rejected their first period contract the government will offer their second period contract to the other firm. If only one firm remains, either i or j, then the government and the firm have to negotiate directly with one another to determine the price of producing the whole of the second period. As such the distribution of the contracts in the first period has a direct effect on the procurement options in the second period. Let θ_1 represent the proportion of work firm two undertakes in period one and θ_2 its proportion in period two. Firm one's proportion of the work is $1-\theta_1$ and $1-\theta_2$ in period one and two respectively. Assume firm two's contract is resolved first each period, though on the equilibrium path it makes no difference to the outcome.

The aim of the government is to complete the project at the lowest possible total cost. One rule the government has to follow to ensure consistency for the industry is if the government has offered a contract with a certain proportion in the first period at a certain price, then if the firm accepts that contract it will be offered at least as much in quantity terms to produce

in the following period. Therefore deciding on the value of θ_1 will impact not only on the first period price but also on the second. As the government sets the rules for the game and responds to the actions of the firms, the players of the game are the two firms. In each period each firm has to choose a price at which they will accept their portion of the contract and a price at which they will undertake the remaining portion. Therefore each firm has an acceptance function $p_t^i(\theta, n) \longrightarrow \Re$, where $i = 1, 2$, $t = 1, 2$ and n represents the number of firms in the industry in period t. The acceptance function expresses the unit price at which they will produce in either period depending upon the number of firms remaining. To reach the price of the contract, the acceptance this price has to be multiplied by the proportion specified by the contract. The solution concept employed is a subgame perfect equilibrium. After the game has been solved to reveal the interactions between the firms the second stage is to devise contracts the government can offer so the firms accept whilst it achieves the lowest possible price.

In the second period there are three possible industrial structures: firm one has a monopoly, firm two has a monopoly or both firms are present in the industry. First assume only one firm remains in the second period. In this case the firm will exploit its monopoly position and charge a price of v as the government is unable to obtain a lower price elsewhere. Now assume both firms remain in the second period after accepting their first period contracts. The price achieved in the final auction for firm one's portion of the project is β; firm two will only drop out of the auction when the price reaches $(1-\theta)\beta$ to ensure no loss is incurred whilst firm one would be prepared to let the price fall to $(1-\theta)\alpha$ before leaving the auction. The result is firm one wins the auction at price $(1-\theta)\beta$. Firm two will therefore accept the contract if the price, $(1-\theta)p_2^1$, is at least $(1-\theta)\beta$. Firm one will also accept only if $p_2^1 \geq \beta$; if the price is lower firm one can go on and in win in the ensuing auction as firm two will also reject the contract. As such the lowest price achievable for firm one's portion of the contract is $(1-\theta)\beta$. In the preceding interactions for firm two's portion of the second period project the auction price will be $\theta\beta$ for the same reason as before; firm two will drop out of the auction if it would

make a loss (when the price falls below $\theta\beta$) whilst firm one could continue as it would still make a profit meaning it would win. As firm one would win the auction it will only accept the contract if the price, p_2^2, is at least $\theta\beta$ whilst firm two will only accept the contract if it covers costs (again $p_2^2 \geq \beta$). For the government, seeking to achieve the lowest possible price if both firms remain on the equilibrium path the minimum price it can pay in the second period is β; the price will only be above β if the government has offered, and a firm accepted, a below cost contract in the first period (as the price of both contracts, if accepted, has to cover the costs incurred).

If one or both firms have rejected their contracts in the first period then, by the rules of the game, their second period contract is offered to the other firm. If firm one rejects its first period contract then unless the government allows for the second period price being $(1-\theta)\beta$ or higher firm two will have to reject the contract to produce firm one's second period portion meaning firm one will win the resulting auction at price $(1-\theta)\beta$. This results in firm one being punished for rejecting its contract by earning a positive profit in the second period! Conversely if firm one rejects its first period contract it will always be punished as firm one can always win the auction for price $\theta\beta$ earning a profit of $\theta(\beta-\alpha)$ or even greater if $p_2^2 > \beta$; the punishment means firm two does not produce in the second period and has to leave the industry. In order for firm two to be able to punish any deviation by firm one it is necessary for the government to give firm one a second period contract priced above its production costs of at least $(1-\theta)\beta$. This coincides with firm one's second period actions, as it will always refuse any contract with $p_2^1 < \beta$. As setting $p_2^1 \geq \beta$ results in a second period profit the government can, to achieve the lowest possible cost, recoup it, either partly or wholly, through firm one's first period contract; should this first period below cost contract be rejected then there is an effective punishment available in the second period. Therefore $p_2^2 \geq \beta$ and $p_2^1 \geq \beta$.

In the first period firm one knows it will be making a profit of at least $(1-\theta)(\beta-\alpha)$ in the second period if it accepts its first period contract whilst firm two will not make a loss if they both remain in the industry. When determining the actions for firm one's portion of

the first period project there are three possibilities: either firm two has already accepted its contract to produce the remaining proportion or either firm one or firm two has won it in the auction. First assume the former, namely firm two has already accepted its contract at price θp_1^2. Therefore in figure 5.1 the top row is under consideration. By firm two's individual rationality constraint the lowest price it will bid in the auction is $(1-\theta)\overline{\alpha}$ where $\overline{\alpha}$ ensures firm two earns a profit of $\theta(p_1^2 + p_2^2 - 2\beta) + (1-\theta)(p_2^1 - \beta)$ over the two periods. If firm two wins a monopoly in the first period it can charge v in the second period however it is unwilling to use the profit it could make if it lost the auction to lower its reservation price in the auction. If it loses the auction it will gain a second period profit of $(1-\theta)(p_2^1 - \beta)$ as firm one rejected their first period contract whilst it will gain its own profit of $\theta(p_2^2 - \beta)$ from accepting its second period contract. Whilst firm two will not compete away any first period profit it has earned if $\theta(p_1^2 - \beta) > 0$ it does have to recoup through a higher reservation price any first period loss if it is incurred, $\theta(p_1^2 - \beta) < 0$. Accordingly firm two's individual rationality constraint is $\min\{0, \theta(p_1^2 - \beta)\} + (1-\theta)(\overline{\alpha} - \beta) + v - \beta = \theta(p_2^2 - \beta) + (1-\theta)(p_2^1 - \beta)$ where $\min\{0, \theta(p_1^2 - \beta)\}$ represents any first period loss. Rearranging the constraint gives $\overline{\alpha} = \beta - \frac{1}{1-\theta}\left[v - \theta p_2^2 - (1-\theta)p_2^1 + \min\{0, \theta(p_1^2 - \beta)\}\right]$. Firm one can only obtain its second period profit of $(1-\theta)(p_2^1 - \alpha)$ if it accepts its first period contract; by rejecting the contract the government can offer firm one's second period portion of the project to firm two for the same price of $(1-\theta)p_2^1$ which will be accepted as $p_2^1 \geq \beta$. This means firm one will leave the auction when the price reaches $(1-\theta)\alpha$ as it has to cover its costs. The result of the auction is a price of $\max\{\alpha, \overline{\alpha}\}$ with firm one winning if $\alpha \leq \overline{\alpha}$. Before the auction both firms have an opportunity to accept or reject the contract. Firm two will accept the contract if $p_1^1 \geq \max\{\alpha, \overline{\alpha}\}$. A basic requirement for acceptance is that the price should at least afford zero profit meaning $p_1^1 \geq \overline{\alpha}$. If $p_1^1 \geq \overline{\alpha} \geq \alpha$ firm two will go on and loose the auction even though it would not have made a loss by accepting the contract. If $p_1^1 \geq \alpha \geq \overline{\alpha}$ firm two will go on and win the auction but at a lower price than if it had accepted the contract. Finally if $\alpha \geq p_1^1 \geq \overline{\alpha}$ firm two, by rejecting the contract, will go on and win the auction at a higher

price than offered by the contract. Thus firm two will accept if $p_1^1 \geq \max\{\alpha, \overline{\alpha}\}$. Firm one also has the opportunity to accept or reject the contract. It will accept the contract, by its individual rationality constraint, if $p_1^1 \geq 2\alpha - p_2^1$. This automatically holds by the rules of the game as the contract prices for each firm have to cover their production costs over the two periods, $p_1^1 + p_2^1 \geq 2\alpha$, but at the lower bound for p_1^1 this leads to zero profit over the two periods. However if it rejects there is the possibility of winning the auction, if $\alpha \leq \overline{\alpha}$, but as the second period profit would be lost this is only profitable if the first period auction offers a greater profit than accepting the government's contracts over two periods, $\overline{\alpha} \geq p_1^1 + p_2^1 - \alpha$. To summarise if firm two has already secured its portion of the production by accepting its contract firm one will accept its first period contract if $\alpha > \overline{\alpha}$ and $p_1^1 \geq 2\alpha - p_2^1$ or if $\alpha \leq \overline{\alpha}$ and $p_1^1 \geq \alpha + \overline{\alpha} - p_2^1$, firm two will accept the contract if $p_1^1 \geq \max\{\alpha, \overline{\alpha}\}$ otherwise the auction will be reached with firm one leaving the bidding at α and firm two leaving at $\overline{\alpha}$. On the course of play firm two will not produce firm one's portion; firm one will always accept its contract unless it could go on and win the auction resulting in a higher profit overall.

If firm two has won its portion of the work in the auction for price θg then it is not guaranteed any second period production as it rejected its own contract. Thus the penultimate row in figure 5.1 is under consideration. If firm one accepts its first period contract then firm two can only produce in the second period if firm one rejects one of the contracts. This affects firm two's reservation price in the auction; although by winning the auction it will gain a monopoly the profit if it looses the auction is only $(1-\theta)(p_2^1 - \beta)$ now. This means the reservation price becomes $\varsigma = \beta - \frac{1}{1-\theta}\left[\upsilon - \theta\beta - (1-\theta)p_2^1 + \min\{0, \theta(g-\beta)\}\right]$. It also affects firm one's reservation price as firm two's rejection of the contract means it will be offered a contract for θ at price θp_2^2 in the second period as long as it either accepts its contract or wins the auction. In the auction firm one is biding for its survival and therefore will leave the auction when the price goes below $(1-\theta)\phi$ with $\phi = \frac{1}{1-\theta}(\alpha - \theta p_2^2)$ ensuring firm one earns zero profit over the two periods. The result of the auction is a price of $\max\{\phi, \varsigma\}$ with firm one winning if $\phi \leq \varsigma$. Firm two's acceptance of the contract remains unaltered as it will accept the contract

only if $p_1^1 \geq \max\{\phi, \varsigma\}$. By firm one's individual rationality constraint, if it were to accept its first period contract, its true reservation price now falls to $\frac{1}{1-\theta}\left[2\alpha - \theta\alpha - \theta p_2^2 - (1-\theta)p_2^1\right]$ as the profit in the second period increases to $(1-\theta)(p_2^1 - \alpha) + \theta(p_2^2 - \alpha)$. It is worth noting this is automatically satisfied by the requirement on the government to cover the costs of the firm.[1] However even if the contract price satisfies the individual rationality constraint it will still be rejected if ς is sufficiently high to allow firm one to win the auction and make a greater first period profit than is available in the second period if it were to accept its contract. As firm one makes a second period profit of $\theta(p_2^2 - \alpha)$ irrespective of whether or not it accepts its contract means the contract will be rejected if $\phi \leq \varsigma$ and $\varsigma \geq p_1^1 + p_2^1 - \alpha$. On the course of play firm two will not produce firm one's portion of the project; firm one can either accept the contract and enjoy the additional second period profit resulting from firm one's rejection of its first period contract or reject the contract and win the auction earning an even greater overall profit.

The final alternative, for firm one's second period production, is that firm one has already won firm two's portion at price h; it makes no difference whether firm one has won firm two's portion by accepting the contract or winning the auction as the consequences, with regards to the second period, are the same. By firm one's individual rationality constraint it is unable to go below $(1-\theta)\gamma$ in the auction, where $\gamma = \alpha - \frac{1}{1-\theta}\left[v - \alpha + \theta(p_2^2 - \alpha) + \min\{0, \theta(h-\alpha)\}\right]$, since winning the auction results in it winning the monopoly but still maintains the profit of $\theta(p_2^2 - \alpha)$ in the second period (following firm two's rejection of its first period contract) and any profit it may have gained from winning firm one's portion of the contract. Firm two, having rejected its contract, will be offered firm one's contract in the second period if it wins the auction (as both firms have rejected their first period contract they have to be offered the other firm's contract in the second period). This means its reservation price in the auction is $\eta = 2\beta - p_2^1$; it is willing to bid away its second period profit as it can only obtain it by

[1] In order for firm one to accept $p_1^1 \geq \frac{1}{1-\theta}\left[2\alpha - \theta\alpha - \theta p_2^2 - (1-\theta)p_2^1\right]$ or, rearranged, $(1-\theta)(p_1^1 + p_2^1) \geq 2\alpha - \theta\alpha - \theta p_2^2$. As $p_1^1 + p_2^1 \geq 2\alpha$, $(1-\theta)(p_1^1 + p_2^1) \geq 2(1-\theta)\alpha$. As such firm one will always accept if $2(1-\theta)\alpha \geq 2\alpha - \theta\alpha - \theta 2^2$ which only requires $p_2^2 \geq \alpha$.

winning the auction. Ergo the price resulting from the auction is $(1-\theta)\max\{\gamma,\eta\}$ with firm one winning if $\gamma \leq \eta$. Firm two will only accept the contract if $p_1^1 \geq \max\{\gamma,\eta\}$. Firm one will accept the contract so long as it offers a greater profit than can be obtained by rejecting it given that, by accepting its own contract, it will gain a monopoly. If $\gamma > \eta$ then firm one will lose the auction so will accept the contract only if $\theta(h-\alpha)+(1-\theta)(p_1^1-\alpha)+v-\alpha \geq \theta(h-\alpha)+\theta(p_2^2-\alpha)$. This, however, always holds.[2] If firm one can win the auction, $\gamma \leq \eta$, it will only accept the contract if $\theta(h-\alpha)+(1-\theta)(p_1^1-\alpha)+v-\alpha \geq \theta(h-\alpha)+(1-\theta)(\eta-\alpha)+v-\alpha$, or, when simplified, $p_1^1 \geq \eta$; since the same profit will be made in the second period it will either accept the contract or win the auction depending on which offers the greater first period price. Again on the course of play firm two will not produce firm one's portion of the project; the only condition under which firm one will reject its first period contract is the one which results in firm two being unable to accept the contract and unable to win the auction.

As the actions for firm one's first period portion have been specified the play for firm two's first period portion can be derived. By backwards induction the different subsequent courses of play have been detailed above meaning firm two knows how firm one will respond when firm two's portion of the project is contracted in the first period. It is important to note that firm two, on the expected course of play, is unable to gain firm one's first period portion of the contract – firm one will only reject the contract it is offered if it can win the auction and earn a larger overall profit. The consequence for firm two is that unless it accepts its contract or wins the auction it will not survive the first period. As such the baseline if it were to accept it contract priced at θp_1^2 is an overall profit of $\theta(p_1^2+p_2^2-2\beta)$ if firm one subsequently accepts its contract or $\theta(p_1^2+p_2^2-2\beta)+(1-\theta)(p_2^1-\beta)$ if it rejects. Given $p_1^2+p_2^2 \geq 2\beta$, as the government has to cover the costs incurred if the contracts are accepted by the rules of the game, firm two will not make a loss if it accepts the contract and therefore there is no reason

[2]The inequality simplifies to $v \geq (1-\theta)(2\alpha-p_1^1)-\theta p_2^2$. As $p_2^2 \geq \beta$ the greatest value p_2^1 can take, given the maximum the government will pay in a period is v and a minimum of $\theta\beta$ is required for firm two's contract, is $p_2^1 = \frac{v-\theta\beta}{1-\theta}$. As $p_1^1+p_2^1 \geq 2\alpha$, the minimum value p_1^1 can take is $p_1^1 = 2\alpha - \frac{v-\theta\beta}{1-\theta}$. When this is put into the rearranged inequality it is clear that it holds.

for the firm not to survive to the second period. However the question of whether firm two can make a higher profit if it rejects its contract remains. In the auction for firm two's portion of the project firm two's reservation price, σ, is dependent on whether or not firm one accepts its own contract. If firm one goes on to accept its contract then firm two will be offered no contracts in the second period and therefore is unable to bid below its production cost as it cannot recoup any losses meaning $\theta\sigma_1 = \theta\beta$. If firm one rejects its contract then, if firm two wins the auction, it is able to obtain a second period profit of $(1-\theta)(p_2^1 - \beta)$ meaning a reservation price of $\theta\sigma_2$ where $\sigma_2 = \frac{1}{\theta}\left[\beta - (1-\theta)p_2^1\right]$; it only obtains the second period profit if it wins the first period auction. In the auction firm one will have a reservation price of $\theta\rho$. By winning the auction firm one makes a profit of $\theta(\rho-\alpha)+(1-\theta)(\max\{p_1^1,\eta\}-\alpha)+v-\alpha$. If firm one looses the auction but goes on to accept its own contract it will lead to a profit of $(1-\theta)(p_1^1-\alpha)+\theta(p_2^2-\alpha)+(1-\theta)(p_2^1-\alpha)$ meaning firm one's reservation value in the auction is $\rho_1 = \frac{1}{\theta}\left[(1-\theta)(p_1^1+p_2^1-\max\{p_1^1,\eta\})+\theta(\alpha+p_2^2)-v\right]$. If firm one goes on to accept its own contract at price p_1^1 then $\sigma_1 > \rho_1$ meaning firm two will always lose the auction.[3] If firm one rejects its first period contract, because it can win the ensuing auction, then the second period profit falls by $(1-\theta)(p_2^1-\alpha)$ meaning the reservation price in the first period auction becomes $\rho_2 = p_2^2 - \frac{1}{\theta}(v-\alpha)$. However $\sigma_2 > \rho_2$ meaning firm one will win the auction again.[4] As such firm two is unable to win the auction for its first period portion of the contract – if it wishes to remain in the second period it has to accept the contract offered to it by the government. For completeness firm one will accept firm two's contract if $p_1^2 > \max\{\rho_2,\sigma_2\}$, the price has to be higher than can be obtained in the auction. On the course of play firm two has no choice but to accept the contract offered by the government; if it rejects firm one will gain the production either by accepting the contract or winning the auction.

[3] If $\sigma_1 > \rho_1$ then $\beta > \frac{1}{\theta}\left[(1-\theta)(p_1^1+p_2^1-p_1^1)+\theta(\alpha+p_2^2)-v\right]$ as σ_1 means firm one accepts its contract. Rearranging the inequality yields $v > (1-\theta)p_2^1+\theta p_2^2-\theta(\beta-\alpha)$. As the right-hand side is increasing in both p_2^2 and p_2^1 the maximum value they can take is $\theta p_2^2+(1-\theta)p_2^1 = v$. Substituting into the inequality and rearranging gives $0 > -\theta(\beta-\alpha)$ which always holds due to the cost differential.

[4] If $\sigma_2 > \rho_2$ then $\frac{1}{\theta}\left[\beta-(1-\theta)p_2^1\right] > p_2^2 - \frac{1}{\theta}(v-\alpha)$. Rearranging this gives $v > \theta p_2^2+(1-\theta)p_2^1-(\beta-\alpha)$ which always holds as $v \geq \theta p_2^2+(1-\theta)p_2^1$.

Given the actions of the firms in relation to the various prices offered by the government are described above it falls on the government to determine the optimal prices for the contracts. How optimal is defined from the government's viewpoint is contentious. The previous chapter described the MoD's original policy as optimal prices being determined by the market in a series of separate competitions but later evolving to include wider factors which, although relevant factors were listed, were never fully specified (for example weighting by importance.) For the purpose of this chapter optimal refers to those prices that achieve the lowest overall cost to the government over the two periods of the project. A defence industrial strategy is defined as a series of contracts, which both firms will accept, that ensures an industrial structure which delivers the project for the lowest total cost. In figure 5.1 the equilibrium path in both period is for firm 2 to accept (A) followed by firm 1 also accepting (A).

Proposition 10 *If the optimal industrial structure is a duopoly, the objective function of the defence industrial strategy is* $\min \theta(p_1^2 + p_2^2) + (1-\theta)(p_1^1 + p_2^1)$ *subject to: (1)* $p_1^2 + p_2^2 \geq 2\beta$, *(2)* $p_1^1 + p_2^1 \geq 2\alpha$, *(3)* $p_2^2 \geq \beta$, *(4)* $p_2^1 \geq \beta$ *and (5)* $p_1^1 + p_2^1 - 2\alpha \geq \overline{\alpha} - \alpha$.

This proposition gives the necessary conditions for both firms to accept the contracts offered them if the government views a duopoly as the optimal industrial structure. The first and second conditions are the firms' individual rationality constraints which, according to the rules of the game, have to be adhered to by the government if the firms accept their contracts. The third and fourth conditions reflect the actions of both firms in the second period as both will reject any contract priced below a unit price of β. The fifth condition is an incentive compatibility constraint, namely the inequality that needs to be satisfied if firm one is to accept its first period contract; the left-hand side gives the profit over two periods from accepting the contract, when both sides are multiplied by $1-\theta$, whilst the right-hand side is the first period profit from rejecting and winning the auction. Condition 1 means firm two will accept its first period contract and condition 3 means it will accept its second period contract. Condition 4 means either firm will accept firm one's second period contract hence condition 5 is necessary to ensure both firms, on the equilibrium path, accept their contracts

(with condition 2 ensuring firm 1 can recoup its costs.)

The lowest possible total cost for the project is for the government to pay each firm's cost of production whilst minimising the size of firm two' portion, $\psi = \theta_{\min}(p_1^2+p_2^2)+(1-\theta_{\min})(p_1^1+p_2^1)$ where ψ represents the total cost of the contract. Rearranging (5) and substituting $p_1^1+p_2^1 = 2\alpha$ into it yields the requirement that $\alpha \geq \overline{\alpha}$ in order for firm one to accept its first period contract – firm one will only accept a contract offering zero profit overall if it is unable to make a profit in the first period auction. Substituting the value of $\overline{\alpha}$ into $\alpha \geq \overline{\alpha}$ gives $v-(1-\theta)(\beta-\alpha) > \theta p_2^2+(1-\theta)p_2^1-\min\{0,\theta(p_1^2-\alpha)\}$. As the right-hand side is increasing in p_2^2 the government needs to minimise this to maximise the range in which $\alpha \geq \overline{\alpha}$. However as $p_2^2 \geq \beta$, the lowest price the government can offer firm two in period two is $p_2^2 = \beta$. Given firm two's individual rationality constraint the government needs to set $p_1^2 = \beta$; this coincides with minimising the right-hand side of the constraint. As the right-hand side is also increasing in p_2^1 the government needs to minimise its value, so $p_2^1 = \beta$. From firm one's individual rationality constraint this implies its first period price is $p_1^1 = \widehat{\alpha} = 2\alpha - \beta$ in the first. As such the government is able to limit the price of each firm to its costs of production if $\beta - \alpha \leq \frac{\Delta}{1-\theta}$, with the lowest cost available if it holds when $\theta = \theta_{\min}$, meaning $\psi = 2\alpha + 2\theta(\beta - \alpha)$.

If this does not hold, $\alpha < \overline{\alpha}$, then the government has to offer more in the first period to induce firm one to accept its first period contract. From (5) it is necessary that $\min\{0,\theta(p_1^2-\alpha)\}+(1-\theta)p_1^1-\theta p_2^2 \geq (1-\theta)(\alpha+\beta)-v$. To ensure this holds the government, again, needs to minimise p_2^2 and maximise p_1^2 meaning $p_1^2 = p_2^2 = \beta$. Given firm one has to be paid $p_2^1 = \beta$ in the second period the lowest price achievable in the first period is $p_1^1 = \widetilde{\alpha} = \alpha - \frac{v-\beta}{1-\theta}$. Firm one cannot be restricted to zero profit as firm two is unable to provide the necessary constraint; firm one has to earn a profit over the two periods equivalent to the profit that it could earn by going to the auction in the first period. However given that it will earn a second period rent this can be used to reduce the first period cost of the project meaning $\overline{\alpha}$ need not be paid. The total cost of the project, if $\beta - \alpha > \frac{\Delta}{1-\theta}$, is $\psi = \alpha + \beta + \theta(\beta - \alpha) - \Delta$.

From the government's perspective the best contract it is able to write is either a legally

binding, complete contract with firm one covering both periods paying α in each period or a contract paying firm one $2\alpha - v$ in the first and v in the second period. The first contract is unfeasible given the lack of commitment available, the second is unfeasible given that firm one could win the contract at a higher price and earn profit as the lowest price firm two can offer in the first period is $2\beta - v$ whilst matching v in the second. Accordingly if the government is to contract and allow a monopoly in the first period the lowest price it could achieve for the whole contract is 2β. If $\beta - \alpha \leq \frac{\Delta}{1-\theta}$, so $\alpha > \overline{\alpha}$, then the cost of the project according to the game is $2\alpha + 2\theta_{\min}(\beta - \alpha) < 2\beta$ whilst if $\beta - \alpha > \frac{\Delta}{1-\theta}$, so $\alpha < \overline{\alpha}$, it is $\alpha + \beta + \theta_{\min}(\beta - \alpha) - \Delta < 2\beta$. Thus if the government splits the contract in the first period and awards work to a firm that is less efficient the government will be able to complete the project at a lower overall cost as firm two's presence in the industry in the second period limits the profit firm one is able to earn – long term efficiency requires short term inefficiency as the higher first period costs of ensuring firm two remains in the industry are more than offset by the competitive benefit it is able to bring in the second period.

Proposition 11 *The optimal defence industrial structure is a duopoly. Firm two produces* $\theta_{\min}$ *for a price of* $\theta_{\min}\beta$ *in both periods. Firm one produces* $1 - \theta_{\min}$ *in both periods and receives* $(1 - \theta_{\min})\beta$ *in period two. If* $\beta - \alpha \leq \frac{\Delta}{1-\theta}$ *then it earns* $(1 - \theta_{\min})(2\alpha - \beta)$ *in period one otherwise it receives* $(1 - \theta_{\min})\left(\alpha - \frac{\Delta}{1-\theta}\right)$.

There are two comparative statics of interest. The first concerns the effect of the cost differential, $\beta - \alpha$, on the cost of the entire project. Assume θ is fixed. If the cost differential is sufficiently small, $\beta - \alpha \leq \frac{v-\beta}{2(1-\theta)}$, then $\bar{\alpha} \leq \widehat{\alpha}$ meaning firm two's buy-in price is below the price necessary for firm one to achieve zero profit. If firm one remains on the equilibrium path it will accept the first period contract priced at $(1-\theta)\widehat{\alpha}$ resulting in zero profit over the two periods; if it rejects and leaves the equilibrium path firm two will accept the contract and obtain a monopoly for the second period. If the cost differential is slightly higher, $\frac{v-\beta}{2(1-\theta)} < \beta - \alpha \leq \frac{v-\beta}{1-\theta}$, then $\widehat{\alpha} < \overline{\alpha} < \alpha$ meaning on the equilibrium path firm one will accept the first period contract priced at $(1-\theta)\widehat{\alpha}$ even though it could earn more in the first period by rejecting. Despite being

able to earn more, $(1-\theta)\overline{\alpha}$, in the ensuing auction this is not sufficient to cover production costs and this loss cannot be recouped in the second period as firm one's second period portion will be offered to firm two who, remaining on the equilibrium path, will accept as it is priced at $(1-\theta)\beta$. Firm one is only able to earn a positive profit if the price that can be achieved in the auction is greater than firm one's marginal cost of production, $\overline{\alpha} > \alpha$. Accordingly if the cost differential is large, $\beta - \alpha > \frac{v-\beta}{1-\theta}$, firm one can reject any contract priced at $(1-\theta)\widehat{\alpha}$ as it can win the auction at a price greater than cost meaning the government has to offer a contract priced at $(1-\theta)\widetilde{\alpha}$. Unsurprisingly the total cost of the project increases with the cost differential between the two firms; if the cost differential is small firm one is constrained to having to produce with normal profit, though if the cost differential is large then firm one is able to use this to earn a positive profit.

The other comparative static of interest concerns how the total cost of the project varies as the split increases holding costs constant. Unsurprisingly the total cost increases in the split; if $\Delta \geq \beta - \alpha$ then firm one is restricted to earning zero profit for all values of θ meaning $\frac{\partial \psi}{\partial \theta} = 2(\beta - \alpha)$. The cost differential represents the transfer of work from the lower cost firm to the higher whilst the 2 results from the rule of the same split being adhered to in both periods. If $\Delta < \beta - \alpha$ then for some lower values of θ firm one is able to earn a positive profit meaning $\widetilde{\alpha}$ can be charged instead of $\widehat{\alpha}$. Accordingly if $\Delta < \beta - \alpha$ and $\theta < \widehat{\theta}$ then $\frac{\partial \psi}{\partial \theta} = \beta - \alpha$ whilst $\frac{\partial \psi}{\partial \theta} = 2(\beta - \alpha)$ if $\theta > \widehat{\theta}$ where $\widehat{\theta} = 1 - \frac{v-\beta}{\beta-\alpha}$. The explanation for the decrease in the slope before $\widehat{\theta}$ stems from $\frac{\partial \overline{\alpha}}{\partial \theta} < 0$. Although decreasing the split decreases the total cost of the project it also raises firm two's buy-in price for firm one's first period portion of the work and consequently makes rejecting the $\widehat{\alpha}$ contract more profitable. When $\theta < \widehat{\theta}$ the government is no longer able to offer the $\widehat{\alpha}$ contract as it will be rejected and has to offer the $\widetilde{\alpha}$ contract which earns firm one a positive profit. This means the savings associated from any further reductions in θ are shared between the government and firm one resulting in the lower $\frac{\partial \psi}{\partial \theta}$.

5.3 Extensions

The base model can be extended in a few ways. This section gives the more basic extensions (discount factors, different size projects, the effect of a partnership if there is a monopoly and a common second period cost shock) before the next two sections present more complex extensions: fixed costs and capacity constraints.

5.3.1 Discount factor

Firstly assume the second period cashflows are discounted at rate δ. The basic model demonstrates that in the second period both firms will charge a unit price of β, firm two will accept its first period contract as long as it earns zero profit overall and that $\overline{\alpha}$ is the key value determining whether firm one accepts or rejects a zero profit contract in the first period. The presence of a discount factor increases $\overline{\alpha}$ to $\overline{\alpha} = \beta - \frac{\delta(v-\beta)}{1-\theta}$ as the second period monopoly profit holds a lower value. If $\alpha > \overline{\alpha}$ then firm one will accept the zero profit contract with $\widehat{\alpha} = \alpha - \delta(\beta - \alpha)$. If $\alpha > \overline{\alpha}$ then firm one will make a profit by rejecting the $\widehat{\alpha}$ contract and only accept $\widetilde{\alpha} = \beta - \delta(\beta - \alpha) - \frac{\delta(v-\beta)}{1-\theta}$ in the first period. The presence of the discount factor increases both $\widehat{\alpha}$ and $\widetilde{\alpha}$ as firm one's second period rent is worth less. It also decreases the cost differential between firm one and firm two within which firm one can be restricted to earning zero profit as the $\widehat{\alpha}$ contract is only possible if $\beta - \alpha < \frac{\delta(v-\beta)}{1-\theta}$.

5.3.2 Different sizes

The base model assumes the project is the same size in each period. Assume now that the first period is of size 1 whilst the second period is of size s. The effect is to alter the second period costs of firm one and firm two to $s\alpha$ and $s\beta$ respectively; the value of v remains unaltered (but $v \geq s\beta$.) Firm two's buy-in price is altered to $\overline{\alpha} = \beta - \frac{\delta(v-s\beta)}{1-\theta}$, which is higher if $s > 1$ as the second period rent is reduced so the monopoly is worth less. If $\alpha > \overline{\alpha}$ then firm one will accept the $\widehat{\alpha}$ contract with $\widehat{\alpha} = \alpha - s\delta(\beta - \alpha)$; if $s > 1$ then $\widehat{\alpha}$ decreases in value as firm two's second period rent, when both firms remain, increases. If $\alpha < \overline{\alpha}$ then firm one will only

accept the $\widetilde{\alpha}$ contract with $\widetilde{\alpha} = \beta - s\delta(\beta - \alpha) - \frac{\delta(v-s\beta)}{1-\theta}$; the effect of s decreases the second term (given firm one's second period rent if both firms remain increases) but increases the third term (as the price it can get by rejecting the $\widehat{\alpha}$ contract has fallen.) However overall the effect is to increase $\widetilde{\alpha}$ if $s > 1$. This means the effect of having a larger second period is to increase the cost differential within which the $\widetilde{\alpha}$ contract is offered, $\beta - \alpha < \frac{\delta(v-s\beta)}{1-\theta}$, and to increase the cost of the total project when the $\widetilde{\alpha}$ contract has to be offered – the reverse holds if the second period work is smaller than the first. In essence this result is the comparative static for v.

5.3.3 Partnership

The previous chapter demonstrated the MoD's move towards a partnership model between it and a monopoly in the shipbuilding industry. This can be modeled by the MoD pursuing competition when there are two firms left in the industry but a partnership when only one firm is left. As before if both firms remain in the second period both charge a unit price of β. However given the partnership if only firm one remains in the second period it only obtains $\alpha + x(v - \alpha)$, where x represents the firm's share of the rent, or loss, under the partnership, with the Government obtaining the remaining $(1 - x)(v - \alpha)$. Likewise if firm two is the only firm in the second period then it obtains $\beta + x(v - \beta)$. The value of x depends on the respective bargaining power of the two sides, though the shipbuilding industry suggests the firm would have more power than the Government.

The effect of having a partnership if a monopoly occurs is to increase $\overline{\alpha}$ as the second period monopoly rent is reduced (so $\overline{\alpha} = \beta - \frac{x\delta(v-\beta)}{1-\theta}$.) As before firm one will accept the $\widehat{\alpha}$ contract if $\alpha > \overline{\alpha}$ (with the value of $\widehat{\alpha}$ unchanged as two firms are present in the second period) and reject the zero profit contract if $\alpha < \overline{\alpha}$. In this case the value of $\widetilde{\alpha}$ increases to $\widetilde{\alpha} = \beta - \delta(\beta - \alpha)\frac{x\delta(v-\beta)}{1-\theta}$ due to the change in $\overline{\alpha}$. The effect of the partnership is not only to increase the total cost of the project if the $\widetilde{\alpha}$ contract is offered but also to increase the range in which the $\widetilde{\alpha}$ contract is offered, if $\beta - \alpha > \frac{x\delta(v-\beta)}{1-\theta}$ then the $\widetilde{\alpha}$ contract has to be

offered. Under this procurement mechanism the MoD's current move towards a partnership with a monopoly needs to cease if this approach to procurement is followed as it can result in a higher project cost with no discernable benefit for the MoD.

5.3.4 Common cost uncertainty

In the model description one cause preventing the signing of a two period contract is uncertainty about second period costs. Assume in the second period there is a common project shock which increases the unit cost for both firms by either $\underline{\varepsilon}$ or $\overline{\varepsilon}$, with $\underline{\varepsilon} < \overline{\varepsilon}$ and the expected value of the shock $\widehat{\varepsilon} = \pi\underline{\varepsilon} + (1-\pi)\overline{\varepsilon}$. Further assume both firms and the government are risk neutral.

In the first period firm two will expect its costs to be $\beta + \widehat{\varepsilon}$ meaning it will only consider firm one's first period portion of the project if it is offered at least $\overline{\alpha} = \beta - \frac{\delta(v-\beta-\widehat{\varepsilon})}{1-\theta}$. If $\alpha > \overline{\alpha}$ then firm one has no alternative but to accept the $\widehat{\alpha}$ contract where $\widehat{\alpha} = \alpha - \delta(\beta - \alpha)$. If $\alpha < \overline{\alpha}$ then firm one is able to earn a first period profit in the auction so the government has to offer the $\widetilde{\alpha}$ contract where $\widetilde{\alpha} = \beta - \delta(\beta - \alpha) - \frac{\delta(v-\beta)}{1-\theta}$. Due to both firms being affected by the same second period cost shock both $\widehat{\alpha}$ and $\widetilde{\alpha}$ are unaltered when compared to the basic model with a discount rate; for example firm one's expected second period rent payment increases to $\beta + \widehat{\varepsilon}$ but its expected costs rise to $\alpha + \widehat{\varepsilon}$ meaning it earns the same overall rent as before. However the presence of second period cost uncertainty increases the total cost of the project; not only is there a direct increase in firms' costs but also an indirect decrease as the cost differential within which firm one can be restricted to earning zero profit is reduced, $\beta - \alpha \leq \frac{\delta(v-\beta-\widehat{\varepsilon})}{1-\theta}$.

5.4 Fixed costs

The cost function of the firm has so far been composed only of variable costs. In this subsection it is assumed each firm has fixed costs, k for firm one and c for firm two. There are two possible scenarios: complete cost advantage and variable cost advantage. Complete cost advantage is defined as firm one having both lower variable and fixed costs than firm two so $k < c$ and

$\alpha + k < \beta + c$. Variable cost advantage occurs when firm one has a lower variable cost but higher fixed costs so $k > c$ but the relationship between $\alpha + k$ and $\beta + c$ is unknown.

5.4.1 Complete cost advantage

First assume the fixed costs are large with $k < c$. If $(1-\theta)(\beta-\alpha) - k < 0$ then the presence of fixed costs limits firm one to produce in both periods at its variable plus fixed costs. Given that both firms remain in the second period firm one can either accept its variable plus fixed cost contract and earn zero profit or reject and earn a profit of $(1-\theta)(\beta-\alpha) - k$. As this is negative no profitable deviation from acceptance exists for firm one in either period; the profit in period two is $(1-\theta)(\beta-\alpha) - k < 0$ whilst the possible profit available in period one from the buy-in price, $\bar{\alpha} = \beta - \frac{\delta(v-\beta-c)}{1-\theta}$, is $(1-\theta)(\beta-\alpha) - \delta(v-c-\beta) - k < 0$. Although the government is able to enforce both firms earning zero profit it will only do so if it is cheaper than auctioning the whole contract for a total price of $(1+\delta)(\beta+c)$. For a split award contract to be cheaper requires $(1-\theta)(\beta-\alpha) > k$ which contradicts the original assumption – although the government can enforce firm one earning zero profit it is cheaper to allow it to earn a profit and not pay the fixed costs of both firms.

If $(1-\theta)(\beta-\alpha) - k > 0$ then firm one can make a second period profit by rejecting a variable plus fixed cost contract – this profit is analogous to the profit made in the absence of fixed costs and the game can be solved in the same way. On the equilibrium path firm two will receive a contract priced at $\theta\beta + c$ in the second period whilst firm one's contract is priced at $(1-\theta)\beta$; if it is priced above this it just increases the cost of the project to the government whilst any lower price will be rejected as firm one can achieve this in the ensuing auction and earn the maximum profit available. As firm two is at a complete cost disadvantage it has no option but to accept its contracts, subject to its individual rationality constraint, however it is possible for firm one to earn a positive profit. If $(1-\theta)(\overline{\alpha}-\alpha) - k > 0$, where $\overline{\alpha} = \beta - \frac{\delta(v-\beta-c)}{1-\theta}$ represents the minimum price firm two will charge to produce firm one's first period portion, firm one can earn a positive profit in the auction and therefore will reject any contract priced

below $\widetilde{\alpha} = \alpha + (1-\delta)(\beta-\alpha) - \frac{\delta(v-\beta-c-k)}{1-\theta}$. If $(1-\theta)(\overline{\alpha}-\alpha)-k \leq 0$ then firm one is unable to make a profit in the auction and will therefore accept a variable plus fixed cost contract which, in the first period, offers a price of $\widehat{\alpha} = \alpha - \delta(\beta-\alpha) + \frac{1+\delta}{1-\theta}k$. The introduction of fixed costs raises $\widehat{\alpha}$ (the government has to pay firm one's fixed costs), $\overline{\alpha}$ (the possible second period rent is reduced by firm two's fixed costs) and $\widetilde{\alpha}$ (the rise in $\overline{\alpha}$ increases the profit firm one can earn).

The question of the optimal θ remains. If $\theta < 1 - \frac{k+\delta(v-\beta-c)}{\beta-\alpha}$ then $(1-\theta)(\overline{\alpha}-\alpha)-k > 0$ meaning firm one will reject a cost based contract as it is able to earn a profit in the first period due to firm two's high buy-in price. Consequently $(1-\theta)\widetilde{\alpha}$ has to be paid to firm one in the first period which leads to the total cost of the project as $\psi = \beta + \delta\alpha + \delta\theta(\beta-\alpha) + (1+\delta)c - \delta(v-\beta-c-k)$ with $\frac{\partial\psi}{\partial\theta} = \delta(\beta-\alpha)$. If $1 - \frac{k+\delta(v-\beta-c)}{\beta-\alpha} \leq \theta \leq 1 - \frac{k}{\beta-\alpha}$ then firm one will not be able to make a profit if it rejects a first period marginal plus fixed cost contract as $(1-\theta)(\overline{\alpha}-\alpha)-k \leq 0$. This means firm one will be offered a price of $(1-\theta)\widehat{\alpha}$ in the first period with the total cost of the project reaching $\psi = (1+\delta)\alpha + \theta(1+\delta)(\beta-\alpha) + (1+\delta)(c+k)$ where $\frac{\partial\psi}{\partial\theta} = (1+\delta)(\beta-\alpha)$. At the upper bound the total cost of project is $(1+\delta)(\beta+c)$. If $\theta > 1 - \frac{k}{\beta-\alpha}$ then firm one is unable to make a profitable deviation in the second period with the result the government would prefer to award a sole source contract priced at $(1+\delta)(\beta+c)$ rather than split the contract. As such no split in this range will be considered; even if $\theta_{\min} > 1 - \frac{k}{\beta-\alpha}$ the government will not split the contract. As would be expected the presence of fixed costs does not alter the marginal effect of θ on total cost for the lower values of θ; choosing the lowest available split leads to the lowest cost for the project. However fixed costs do rule out some of the splits available in their absence and thus truncates the cost curve if k is small.

5.4.2 Variable cost advantage

If $k > c$ but $\alpha + k < \beta + c$ then the game is the same as for complete cost advantage. Although firm two has lower fixed costs the disadvantage of higher variable costs means it is unable to win any auction against firm one. For firm one the option of rejecting any contract priced

below $(1-\theta)\beta$ remains if $(1-\theta)(\beta-\alpha)-k>0$ in the second period given the lowest firm two can bid is $(1-\theta)\beta$ (assuming firm two has accepted its second period contract so its fixed costs have already been paid.) Despite firm one's higher fixed costs these will always be covered by firm one accepting its second period contract, with either $\widehat{\alpha}$ or $\widetilde{\alpha}$ in the first period, and therefore it is able to go as low as $\theta\alpha$ in the second period auction for firm two's portion whilst firm two is unable to go below $\theta\beta+c>\theta\alpha$. In the first period firm one's options are the same as before whilst for firm two to deviate requires $\theta(\overline{\beta}-\beta)-c>0$ where $\overline{\beta}$ represents the price firm one will charge to produce firm two's first period portion, $\overline{\beta}=\alpha-\frac{1}{\theta}\left[x+\delta(v-\alpha-k)\right]$ where x is the firm one's project profit depending on whether $\widehat{\alpha}$ or $\widetilde{\alpha}$ is charged in the first period. The constraint ensures both that firm two wins the auction and that it can make a profit if it does reject its cost contract and win the auction. Unfortunately for firm two the constraint never holds.[5] As such no profitable deviation from accepting its contract in both periods exists for firm two. Firm two is unable to take advantage of its fixed cost advantage due to the marginal cost disadvantage which causes it to loose any auctions (where the profit is made.) However the effect of the increase in k is to increase the possibility that a monopoly will be awarded (as the increase in k decreases the threshold at which a monopoly is preferred, $\theta_{\min}>1-\frac{k}{\beta-\alpha}$.

Even if $\alpha+k>\beta+c$ firm two faces the problem of earning a positive profit – firm two is still unable to win any auction due to its higher variable costs. The game does, however, have one difference to the complete cost advantage game. If the government offers a sole-source contract then the price will now be $\alpha+k$ with firm two winning the production and earning a positive profit. This now has to form the constraint against which the split award contracts can be judged. If firm one is to be held to a zero profit contract with $\widehat{\alpha}$ in the first period then it is cheaper for the government to award a sole source contract to firm two.[6] Likewise

[5]Rearranging the constraint yields $\theta\overline{\beta}>\theta\beta+c$. If firm one is restricted to $\widehat{\alpha}$ then $x=0$ so $\overline{\beta}=\alpha-\frac{\delta}{\theta}(v-\alpha-k)$ and $\theta\overline{\beta}=\theta\alpha-\delta(v-\alpha-k)<\theta\beta+c$ as $\beta>\alpha$. If firm one is able to earn a profit then $x=(1-\theta)(\beta-\alpha)-k-\delta(v-\beta-c)>0$ and $\theta\overline{\beta}=\theta\alpha-x-\delta(v-\alpha-k)<\theta\beta+c$ as before. Note it is unlikely that firm one will compete away its profit if $x>0$.

[6]For the total cost of a split award contract to be less than the sole source contract requires $(1+\delta)\alpha+\theta(1+$

if firm one can make a profit with the first period contract priced at $\widetilde{\alpha}$ then the sole source contract is cheaper than the split award contract.[7] Accordingly if $\alpha + k < \beta + c$ firm one will not gain any production as the government will award a sole source contract to firm two. This is the reverse of the preceding argument in that for all possible first period splits of the contract the lowest cost option is to allow firm two to obtain a monopoly in the first period; although firm one is able to constrain firm two to earning zero profit the price that has to be paid to firm one to cover its fixed costs is too high. Therefore despite it being value for money for firm two to constrain firm one rents' when it is less efficient most of the time, it is never value for money for firm one to constrain firm two when the situation is reversed. This and the preceding subsections gives rise to the following proposition.

Proposition 12 *The presence of fixed costs can switch the optimal industrial structure from a duopoly to a monopoly.*

Although this is a fairly obvious proposition it reiterates the role fixed costs can play in the industrial structure and that this role remains unaltered using this procurement mechanism. Given there is an upper bound on the extent to which the firms are able to increase their fixed costs the question of whether this will have any effect on the capital investments to reduce variable costs made by the firms arises.

Assume there is a pre-game concerning investment. Firm one is able to increase its fixed costs by i in each period to reduce their variable costs by $f(i)$ where $f'(i) > 0$, $f''(i) < 0$ and firm one's total costs in each period are $\alpha - f(i) + k + i$. Likewise firm two is able to increase its fixed costs by y in each period to reduce their variable costs by $g(y)$ where $g'(y) > 0$,

$\delta)(\beta - \alpha) + (1+\delta)(c+k) < (1+\delta)(\alpha+k)$ where the left-hand side is the cost of the split award contract and the right-hand side the cost of the sole source contract. Rearranging the inequality yields $\theta < \frac{-c}{\beta-\alpha}$. Therefore for all plausible values of θ, $0 < \theta < 1$, a sole source contract is cheaper.

[7]If the split award contract is cheaper then $\beta + \delta\alpha + \delta\theta(\beta-\alpha) + (1+\delta)c - \delta(v-\beta-c-k) < (1+\delta)(\alpha+k)$ where the left-hand side is the cost of the split award contract and the right-hand side the cost of the sole source contract. Rearranging the inequality gives $\theta < \frac{(1+\delta)(k-c)+\delta(v-\beta-c-k)-(\beta-\alpha)}{\delta(\beta-\alpha)}$. In order for firm one to be offered the $\widetilde{\alpha}$ contract the total cost of the $\widetilde{\alpha}$ contract is greater than the total cost of the $\widehat{\alpha}$ contract. This means $\beta + \delta\alpha + \delta\theta(\beta-\alpha) + (1+\delta)c - \delta(v-\beta-c-k) > (1+\delta)\alpha + \theta(1+\delta)(\beta-\alpha) + (1+\delta)(c+k)$ or, rearranged, $0 > (1+\delta)k + \delta(v-\beta-c-k) - (1-\theta)(\beta-\alpha)$. Substituting this into the previous inequality means $\theta < \frac{(1+\delta)(k-c)+\delta(v-\beta-c-k)-(\beta-\alpha)}{\delta(\beta-\alpha)} < 0$ so for no positive values of θ is the split award contract cheaper.

$g''(y) < 0$ and firm two's total costs in each period are $\beta - g(y) + c + y$. Total costs are minimised where $f'(i^*) = 1$ and $g'(i^*) = 1$ so if $\alpha - f(i^*) + k + i^* \leq \beta - g(y^*) + c + y^*$ then firm one has the possibility of earning a profit but if the inequality is reversed and is strict firm two will earn the profit. Unfortunately these are not the optimal investments to minimise the total cost of the project – irrespective of whether $\widehat{\alpha}$ or $\widetilde{\alpha}$ is offered to firm one the total cost of minimising the project[8] occurs where $f'(i^{**}) = \frac{1}{1-\theta}$ and $g'(y^{**}) = \frac{1}{\theta}$ with $i^* > i^{**}$ and $y^* > y^{**}$. If $\alpha - f(i) + k + i \leq \beta - g(y) + c + y$ for all $i \in [i^{**}, i^*]$ and $y \in [y^{**}, y^*]$ then firm two has no opportunity to earn a profit and the total project cost minimising investments will be made by the two firms. If it does not hold, especially when $\alpha - f(i^{**}) + k + i^{**} \leq \beta - g(y^{**}) + c + y^{**}$ but $\alpha - f(i^*) + k + i^* > \beta - g(y^*) + c + y^*$, firm one will increase its investment above i^{**} to ensure that it will be awarded a production contract by the government. The key implication is that $i \geq i^{**}$ and $y \geq y^{**}$ – the procurement system will not result in under-investment by the firms.

5.5 Capacity constraints

Previously it has been assumed that a firm is able to produce the whole contract in the second period irrespective of the proportion it produced in the first period. This assumption is now relaxed by imposing second period capacity constraints – a firm is now only able to produce a multiple z of its first period production. As before let θ_1 represent firm two's first period split but now let firm one produce λ_1 where $\theta_1 + \lambda_1 \geq 1$; the inequality stems from the possibility of the government wishing to increase the first period work to enable more competition in the second. Accordingly in the second period the maximum firm one is able to produce is $z\lambda_1$ whilst firm two can produce $z\theta_1$. When combined these provide a constraint within which the government has to award production in the second period, $\lambda_2 \in [\max\{0, 1 - z\theta_1\}, \min\{1, z\lambda_1\}]$ and $\theta_2 \in [\max\{0, 1 - z\lambda_1\}, \min\{1, z\theta_1\}]$. Let $\overline{\lambda} = \frac{1}{z}$ and $\overline{\theta} = \frac{1}{z}$. If $\theta_1 < \overline{\theta}$ firm one will be guaranteed a certain portion of production in the second period as firm two is unable to

[8]For $\widetilde{\alpha}$ not only is the total cost of the project to the government minimised but the profit earned by firm one is also maximised at the same value.

produce the whole second period contract. Similarly firm two will be guaranteed a certain portion of production in the second period if $\lambda_1 < \overline{\lambda}$. If $\theta_1 > \overline{\theta}$ then firm two is able to produce the whole second period project meaning firm one is not guaranteed any second period production. If $\lambda_1 > \overline{\lambda}$ firm two is not guaranteed any second period production as firm one is able to undertake it all. In a slight alteration of the rules if a firm accepts its first period contract it will be guaranteed a portion of the second period production but not necessarily the same proportion as the first period. This is analogous to previous sections where firm two has been awarded $\theta_{\min}$ in both periods so some second period production has been ensured but as $\lambda_1 + \theta_1 \geq 1$ guaranteeing the same proportions in the second period will lead to the project being too large and expensive in the second period than is necessary (as it provides no benefits).

5.5.1 Limited expansion

If only limited expansion is available in the second period, $z < 2$, then there are four possibilities in the second period: both firms are guaranteed production, only one firm is guaranteed production or neither is guaranteed any production and both can compete for the whole contract.

For comparison firstly assume that the government awards $\lambda \geq \overline{\lambda}$ to firm one and $\theta \geq \overline{\theta}$ to firm two in period one; this enables both firms to produce the whole second period contract. The first period cost of complete second period competition is to have a greater first period project as $\overline{\lambda} + \overline{\theta} > 1$ given $z < 2$. To minimise the second period cost the government will award firm two $\theta_{\min}$ and firm one $1 - \theta_{\min}$ both for a unit price of β. As firm two is unable to earn a profit in the first period it will be offered θ priced at $\theta\beta$. Firm two's reservation price in the auction for firm one'e first period contract is $\overline{\alpha} = \beta - \frac{\delta}{\lambda}(\upsilon - \beta)$. Firm one is unable to earn a first period profit if $\alpha \geq \overline{\alpha}$ and will be offered, and accept, $\lambda\widehat{\alpha}$ where $\widehat{\alpha} = \alpha - \frac{\delta(1-\theta_{\min})}{\lambda}(\beta - \alpha)$. If $\alpha < \overline{\alpha}$ then the government is unable to prevent firm one earning a profit and has to offer $\lambda\widetilde{\alpha}$ in the first period where $\widetilde{\alpha} = \beta - \frac{\delta}{\lambda}(\upsilon - \beta) - \frac{\delta}{\lambda}(1 - \theta_{\min})(\beta - \alpha)$.

The total cost of the project is $\psi(\widehat{\alpha}) = \lambda\alpha + \delta(1-\theta_{\min})\alpha + \theta\beta + \delta\theta_{\min}\beta$ if the $\widehat{\alpha}$ contract is offered or $\psi(\widetilde{\alpha}) = \lambda\beta - \delta(v-\beta) + \delta(1-\theta_{\min})\alpha + \theta\beta + \delta\theta_{\min}\beta$ if the $\widetilde{\alpha}$ has to offered. As the total cost is increasing in both λ and θ the cheapest project entails $\lambda = \overline{\lambda}$ and $\theta = \overline{\theta}$. The cost of this split is decreasing in z as $\frac{\partial\psi(\widehat{\alpha})}{\partial\widetilde{\alpha}} = \frac{-(\alpha+\beta)}{z^2}$ and $\frac{\partial\psi(\widetilde{\alpha})}{\partial\widetilde{\alpha}} = \frac{-2\beta}{z^2}$; an increase in z lowers the size of the first period project and thus reduces the first period cost. This split, however, is only feasible if $z \geq \frac{2\beta}{\beta+\delta[v-\alpha-\theta_{\min}(\beta-\alpha)]}$; if z is too small then it is cheaper for the government to offer a sole source contract for price $\beta + \delta\beta$.

The question of this section is does the government have to ensure both firms can compete for the whole second period project to achieve the lowest overall price. Consider the alternative case where $\lambda < \overline{\lambda}$ and $\theta < \overline{\theta}$, meaning both firms are unable to produce the whole project in the second period and therefore both firms are guaranteed production in the second period. Assume λ is large, given firm one's cost advantage, so firm two is guaranteed to produce $\max\{1-z\lambda, \theta_{\min}\}$ whilst firm one is guaranteed $1-z\theta$. Assume $\theta_{\min} < 1-z\lambda$. In the second period firm two is able to charge $(1-z\lambda)v$ whilst firm one will earn $(1-z\theta)v + (z\lambda+z\theta-1)\beta$ on the remaining portion of the project; firm one will charge a unit price of v on the portion firm two is unable to produce and β on the portion both firms are able to produce. In the first period firm two is unable to reject a contract that offers zero profit overall as firm one would always be willing to accept and increase its profit. This means firm two will be offered $\theta\widehat{\beta}$ for its first period contract where $\widehat{\beta} = \beta - \frac{\delta}{\theta}(1-z\lambda)(v-\beta)$. Firm two is able to bid $\lambda\overline{\alpha}$ for firm one's first period contract where $\overline{\alpha} = \beta - \delta z(v-\beta)$ as it has to earn some second period profit, $(1-z\lambda)(v-\beta)$, to ensure it does not make a loss on its own contracts. If $\alpha > \overline{\alpha}$ then firm one will accept the contract offering zero profit overall so $\widehat{\alpha} = \alpha - \frac{\delta}{\lambda}(1-z\theta)(v-\alpha) - \frac{\delta}{\lambda}(z\lambda+z\theta-1)(\beta-\alpha)$. If $\alpha < \overline{\alpha}$ then the government has to offer firm one $\lambda\widetilde{\alpha}$ in the first period where $\widetilde{\alpha} = \beta - \frac{\delta}{\lambda}[z\lambda(v-\beta) + (1-z\theta)(v-\alpha) + (z\lambda+z\theta-1)(\beta-\alpha)]$. The total costs of the two contracts are $\psi(\widehat{\alpha}) = \lambda\alpha + \theta\beta + \delta\beta - \delta z\lambda(\beta-\alpha)$ and $\psi(\widetilde{\alpha}) = \lambda\beta + \theta\beta + \delta\beta - \delta z\lambda(v-\alpha)$. For both contracts $\frac{\partial\psi}{\partial\lambda} < \frac{\partial\psi}{\partial\theta}$ meaning the optimal split approaches $\lambda = 1-\theta_{\min}$ and $\theta = \theta_{\min}$ if $z < \frac{1}{1-\theta_{\min}}$. The reason it only approaches the optimal split when

z is small is that whilst both $\lambda < \overline{\lambda}$ and $\theta < \overline{\theta}$ hold, $\theta_{\min} < 1 - z\lambda$ does not (as it requires $z < 1$ if $\lambda = 1 - \theta_{\min}$). If z is sufficiently large, so $z > \frac{1}{1-\theta_{\min}}$, the scenario where $\lambda > \overline{\lambda}$ and $\theta < \overline{\theta}$ is entered.

Accordingly consider the case where $\lambda < \overline{\lambda}$, $\theta < \overline{\theta}$ and $\theta_{\min} > 1 - z\lambda$. In the second period firm two is now guaranteed to produce $\theta_{\min}$ for a unit price of v. Although firm two only need be awarded $1 - z\lambda$ it has to be given more to make the production feasible and knowing this it is able to charge v for all its production despite firm one being able to compete for part of it. Firm one will produce the remainder of the second period contract for $(1 - z\theta)v + (z\theta - \theta_{\min})\beta$ charging v for its guaranteed portion of the contract and β on the portion that firm two can compete for. As firm two is restricted to earning zero profit it will be offered $\theta\widehat{\beta}$ for its first period contract where $\widehat{\beta} = \beta - \frac{\delta\theta_{\min}}{\theta}(v - \beta)$. Furthermore firm two will leave the auction for firm one's first period portion of the work at $\overline{\alpha} = \beta - \frac{\delta}{\lambda}(1 - \theta_{\min})(v - \beta)$. This is higher than before as there is less second period rent available to firm two as some of it has already been allocated to firm two in order for the project to be completed. If $\alpha > \overline{\alpha}$ then firm one will be offered a zero profit contract where $\widehat{\alpha} = \alpha - \frac{\delta}{\lambda}[(1 - z\theta)(v - \alpha) + (z\theta - \theta_{\min})(\beta - \alpha)]$. If $\alpha < \overline{\alpha}$ then the government is unable to prevent firm one earning a profit meaning it has to offer $\widetilde{\alpha} = \beta - \frac{\delta}{\lambda}[(1 - \theta_{\min})(v - \alpha) + (1 - z\theta)(v - \beta)]$. The total costs of the project is either $\psi(\widehat{\alpha}) = \lambda\alpha + \theta\beta + \delta(1 - \theta_{\min})\alpha + \delta\theta_{\min}\beta$ or $\psi(\widetilde{\alpha}) = \lambda\beta + \theta\beta + \delta\beta - \delta(1 - \theta_{\min})(v - \alpha)$. As $\frac{\partial\psi(\widehat{\alpha})}{\partial\lambda} < \frac{\partial\psi(\widehat{\alpha})}{\partial\theta}$ the optimal split is $\lambda = 1 - \theta_{\min}$ and $\theta = \theta_{\min}$ if the $\widehat{\alpha}$ contract is offered. As firm one is restricted to zero profit this split is cheaper than increasing firm two's share to allow it to compete for the whole contract in the second period. However $\frac{\partial\psi(\widetilde{\alpha})}{\partial\lambda} = \frac{\partial\psi(\widetilde{\alpha})}{\partial\theta}$ meaning there is no difference to total cost whether λ or θ is increased so long as $\lambda + \theta = 1$. Irrespective of which split is chosen, providing $\lambda + \theta = 1$, it is cheaper for the government to allow only partial competition in the second period rather than complete competition.[9]

[9]Let the subscript c denote the scenario where there is complete competition and p when there is partial competition in the second period. Note that $\psi(\widetilde{\alpha}_p)$ is fixed and $\frac{\partial\psi(\widetilde{\alpha}_c)}{\partial z} < 0$ so the price inequality needs to be taken at the largest value of z permissable. For the partial competition case to be valid requires $z < \min\left\{\frac{1}{\theta_{\min}}, \frac{1}{1-\theta_{\min}}\right\}$. As $\theta_{\min} < \frac{1}{2}$, $z = \frac{1}{1-\theta_{\min}}$ forms the upper bound and $\overline{\lambda} = \overline{\theta} = 1 - \theta_{\min}$. Given this, $\overline{\alpha}_c > \overline{\alpha}_p$ at $\overline{\lambda} = 1 - \theta_{\min}$ meaning there are three possible cases. Firstly if $\alpha < \overline{\alpha}_p$ then in both cases

Next consider the case where $\lambda > \overline{\lambda}$ and $\theta < \overline{\theta}$. In this scenario firm one still has the possibility to earn a profit however this possibility is now denied to firm two (as firm one can produce the whole of the second period contract but firm two cannot). As before it is cheapest for firm two to produce $\theta_{\min}$ for $\theta_{\min}\beta$ in the second period but firm two can produce a further $z\theta - \theta_{\min}$ if necessary. In the second period firm one is guaranteed a portion of $1 - z\theta$ at price v as firm two is unable to produce it. Firm one will also produce the remaining $z\theta - \theta_{\min}$ though only for β as firm two is also able to produce this portion. Firm two is unable to earn a profit so will accept $\theta\beta$ for its first period contract. Let $\overline{\alpha} = \beta - \frac{\delta}{\lambda}(v - \beta)$. Firm one is unable to earn a profit if $\alpha \geq \overline{\alpha}$ and is restricted to the $\widehat{\alpha}$ contract where $\widehat{\alpha} = \alpha - \frac{\delta}{\lambda}(1 - z\theta)(v - \alpha) - \frac{\delta}{\lambda}(z\theta - \theta_{\min})(\beta - \alpha)$. If $\alpha < \overline{\alpha}$ then firm one is able to earn a profit in the first period and will accept the $\widetilde{\alpha}$ contract where $\widetilde{\alpha} = \beta - \frac{\delta}{\lambda}(v - \beta) - \frac{\delta}{\lambda}(1 - z\theta)(v - \alpha) - \frac{\delta}{\lambda}(z\theta - \theta_{\min})(\beta - \alpha)$. An increase in λ raises $\widetilde{\alpha}$ due to λ increasing $\overline{\alpha}$. An increase in θ also raises $\widetilde{\alpha}$, but this is now due to the second period rent being reduced, and also the first period procurement price for firm two. The total cost of the project with the $\widehat{\alpha}$ contract is $\psi(\widehat{\alpha}) = \lambda\alpha + \delta(1 - \theta_{\min})\alpha + \theta\beta + \delta\theta_{\min}\beta$. With the $\widetilde{\alpha}$ the cost increases to $\psi(\widetilde{\alpha}) = \lambda\beta - \delta v + \delta\beta + \delta(1 - \theta_{\min})\alpha + \theta\beta + \delta\theta_{\min}\beta$. If firm one can be restricted to the marginal cost contract then the cost is increasing in both λ and θ but $\frac{\partial\psi(\widehat{\alpha})}{\partial\lambda} < \frac{\partial\psi(\widehat{\alpha})}{\partial\theta}$. As such the optimal first period split is $\lambda = 1 - \theta_{\min}$ and $\theta = \theta_{\min}$, providing $z \geq \frac{1}{1-\theta_{\min}}$, since both firms are restricted to cost it allows for the lowest project cost. If firm one has to be offered the $\widetilde{\alpha}$ contract then $\frac{\partial\psi(\widetilde{\alpha})}{\partial\lambda} = \frac{\partial\psi(\widetilde{\alpha})}{\partial\theta}$. As for smaller values of z it makes no difference whether λ or θ is increased so long as $\lambda + \theta = 1$ for $z\lambda > 1$ and $z\theta < 1$. The total cost of the project with partial second period competition for large values of z is also cheaper than the

$\widetilde{\alpha}$ has to be offered to firm one. If the partial second period competition is cheaper then $\psi(\widetilde{\alpha}_p) < \psi(\widehat{\alpha}_c)$ (given $\psi(\widehat{\alpha}_c) < \psi(\widetilde{\alpha}_c)$) so $\beta + \delta\beta - \delta(1 - \theta_{\min})(v - \alpha) < \overline{\lambda}\alpha + \overline{\theta}\beta + \delta(1 - \theta_{\min})\alpha + \delta\theta_{\min}\beta$ which rearranges to $\beta - 2\theta_{\min}\beta > -\delta\theta_{\min}(v - \beta)$ which always holds as $\theta_{\min} < \frac{1}{2}$. Alternatively if $\overline{\alpha}_p < \alpha < \overline{\alpha}_c$, so if there is complete second period competition then firm one is offered $\widetilde{\alpha}$ whilst if there is only partial competition then $\widehat{\alpha}$ need be offered, then the partial competition option offers the lower cost as both firms are restricted to zero profit without the excess production and positive profit for firm one of the complete competition case. Finally if $\overline{\alpha}_c < \alpha$, so $\widehat{\alpha}$ is offered in both cases, then the option offering partial competition in the second period is cheaper as both firms are restricted to earning zero profit but with partial second period competition it is without the excess first period production.

project associated with complete second period competition.[10]

The final alternative is $\lambda < \overline{\lambda}$ and $\theta > \overline{\theta}$. This means firm two is able to produce the whole contract in the second period but firm one is only able to produce part of it. In the second period it is cheapest for firm one to produce $z\lambda$ and firm two to produce $1 - z\lambda$, assuming $1 - z\lambda \geq \theta_{\min}$. Firm two is unable to earn a positive profit overall meaning it will be offered $\widehat{\beta} = \beta - \frac{\delta}{\theta}(1 - z\lambda)(v - \beta)$. Firm one will receive $z\lambda\beta$ in period two, so in period one will be offered $\lambda\widehat{\alpha}$ if $\alpha > \overline{\alpha}$, where $\widehat{\alpha} = \alpha - \delta z(\beta - \alpha)$ and $\overline{\alpha} = \beta - \frac{\delta}{\lambda}(v - \beta)$, or $\lambda\widetilde{\alpha}$ if $\alpha < \widetilde{\alpha}$, where $\widetilde{\alpha} = \beta - \delta z(\beta - \alpha) - \frac{\delta}{\lambda}(v - \beta)$. The total cost of the project is either $\psi(\widehat{\alpha}) = \lambda\alpha + \theta\beta + \delta z\lambda\alpha + \delta(1 - z\lambda)\beta$ or $\lambda\beta + \theta\beta + \delta\beta - \delta(v - \beta) - \delta z\lambda(\beta - \alpha)$. However in both cases $\frac{\partial\psi}{\partial\lambda} < \frac{\partial\psi}{\partial\theta}$ meaning the government wishes to minimise θ and maximise λ. However eventually one of the constraints will be met (either $\lambda = \overline{\lambda}$ or $\theta = \overline{\theta}$) and one of the previously described scenarios will be entered (with the process of minimising θ and maximising λ continuing.)

If $1 - z\lambda < \theta_{\min}$ then in the second period firm two will produce $\theta_{\min}$ and receive $\theta_{\min}v$; as firm two is required for the project to be completed it can demand v for all of its second period production. Firm one will produce the remaining $1 - \theta_{\min}$ for $(1 - \theta_{\min})\beta$ as firm two is also able to produce it. In the first period firm one will be offered the $\widehat{\alpha}$ contract if $\alpha > \overline{\alpha}$, where $\overline{\alpha} = \beta - \frac{\delta}{\lambda}(1 - \theta_{\min})(v - \beta)$ and $\widehat{\alpha} = \alpha - \frac{\delta}{\lambda}(1 - \theta_{\min})(\beta - \alpha)$, or the $\widetilde{\alpha}$ contract if $\alpha < \overline{\alpha}$, with $\widetilde{\alpha} = \beta - \delta(1 - \theta_{\min})(v - \alpha)$. The total cost of the project is either

[10] As before let the subscript c denote when the first period split allows complete competition in the second period and p if there is only partial. Assume $z > \frac{1}{1-\theta_{\min}}$; if this does not hold then the previous section applies (with $\lambda < \overline{\lambda}$, $\theta < \overline{\theta}$ and $\theta_{\min} > 1 - z\lambda$.) Note that $\overline{\alpha}_p \geq \overline{\alpha}_c$ with equality if $\lambda = \overline{\lambda}$. Therefore there are three possible cases. If $\overline{\alpha}_p > \overline{\alpha}_c > \alpha$ then firm one is able to earn a profit in both cases. In order for the contract offering partial second period competition to be cheaper requires $\lambda\beta - \delta v + \delta\beta + \delta(1 - \theta_{\min})\alpha + \theta\beta + \delta\theta_{\min}\beta < \overline{\lambda}\beta - \delta(v - \beta) + \delta(1 - \theta_{\min})\alpha + \overline{\theta}\beta + \delta\theta_{\min}\beta$. This reduces to $\beta < \overline{\lambda}\beta + \overline{\theta}\beta$ which always holds. If $\overline{\alpha}_p > \alpha > \overline{\alpha}_c$ then firm one will receive $\widehat{\alpha}$ if there is complete competition in the second period but $\widetilde{\alpha}$ if there is only partial competition. For the partial competition option to be cheaper requires $\lambda\beta - \delta v + \delta\beta + \delta(1 - \theta_{\min})\alpha + \theta\beta + \delta\theta_{\min}\beta < \overline{\lambda}\alpha + \delta(1 - \theta_{\min})\alpha + \overline{\theta}\beta + \delta\theta_{\min}\beta$. This reduces to $\alpha > \frac{1-\overline{\theta}}{\overline{\lambda}}\beta - \frac{\delta}{\overline{\lambda}}(v - \beta)$ which holds as $\alpha > \overline{\alpha}_c = \beta - \frac{\delta}{\lambda}(v - \beta)$ and $\frac{1-\overline{\theta}}{\overline{\lambda}} = z - 1 < 1$. This also requires $\overline{\alpha}_p > \alpha$. If this inequality does not hold then in both cases firm one will be offered the $\widehat{\alpha}$ contract. However this will always be cheaper when there is only partial competition as the government does not have to pay for the excess first period production as it does not being any second period benefits.

$\psi(\widehat{\alpha}) = \lambda\alpha + \theta\beta + \delta(1-\theta_{\min})\alpha + \delta\theta_{\min}\beta$ or $\psi(\widetilde{\alpha}) = \lambda\beta + \theta\beta + \delta\beta - \delta\lambda(1-\theta_{\min})(v-\alpha)$. Irrespective of the contract offered $\frac{\partial\psi}{\partial\lambda} < \frac{\partial\psi}{\partial\theta}$ meaning the government will seek to minimise θ and maximise λ. As before one of the constraints will be met and a different scenario entered.

The presence of capacity constraints with only limited second period expansion possible does not require the government to increase the size of the first period project to ensure there is competition available for the whole of the second period project. Rather, the contracts can be designed by the government to acknowledge that second period rents will be earned and therefore lower payments can be made in the first period.

5.5.2 Rapid expansion

Now assume $z > 2$. There are two major differences between this and the limited expansion case. The first is that irrespective of the split one firm will always be able to produce the whole of the second period project. The second is that complete competition for the second period can now be ensured without having to pay for excess production in the first period.

First assume $\lambda > \overline{\lambda}$ and $\theta > \overline{\theta}$ so both firms are able to compete for the whole of the second period contract. In the second period the cheapest split available is for firm two to produce $\theta_{\min}$ for $\theta_{\min}\beta$ and firm one $1-\theta_{\min}$ for $(1-\theta_{\min})\beta$. In the first period firm two will be offered, and accept, $\theta\beta$ to produce θ. Firm two's buy-in price is $\overline{\alpha} = \beta - \frac{\delta}{\lambda}(v-\beta)$ which means firm one is restricted to the $\widehat{\alpha}$ contract if $\overline{\alpha} < \alpha$, where $\widehat{\alpha} = \alpha - \frac{\delta}{\lambda}(1-\theta_{\min})(\beta-\alpha)$, or can receive the $\widetilde{\alpha}$ contract if $\overline{\alpha} > \alpha$, where $\widetilde{\alpha} = \beta - \frac{\delta}{\lambda}[v - \beta + (1-\theta_{\min})(\beta-\alpha)]$. The total cost of the project is either $\psi(\widehat{\alpha}) = \lambda\alpha+\theta\beta+\delta(1-\theta_{\min})\alpha+\delta\theta_{\min}\beta$ or $\psi(\widetilde{\alpha}) = \lambda\beta+\theta\beta+\delta(1-\theta_{\min})\alpha+\delta\theta_{\min}\beta-\delta(v-\beta)$. If the $\widehat{\alpha}$ contract is offered then $\frac{\partial\psi(\widehat{\alpha})}{\partial\lambda} < \frac{\partial\psi(\widehat{\alpha})}{\partial\theta}$ so the optimal split approaches $\lambda = 1-\overline{\lambda}$ and $\theta = \overline{\theta}$ and the case where $\lambda > \overline{\lambda}$ and $\theta < \overline{\theta}$ needs to be considered. If the $\widetilde{\alpha}$ contract is offered then $\frac{\partial\psi(\widetilde{\alpha})}{\partial\lambda} = \frac{\partial\psi(\widetilde{\alpha})}{\partial\theta}$ meaning the government is indifferent about the first period split so long as $\lambda + \theta = 1$, $\lambda > \overline{\lambda}$ and $\theta > \overline{\theta}$.

Next consider the case where $\lambda > \overline{\lambda}$ and $\theta < \overline{\theta}$ so firm one can produce the whole of the second period contract but firm two cannot. In this case firm two's second period contract is

$\theta_{\min}\beta$ whilst firm one has to be offered $(1-z\theta)v+(z\theta-\theta_{\min})\beta$ (with v charged for the portion firm two is unable to produce and β for the remainder). In the first period firm two is unable to reject $\theta\beta$ and will offer $\overline{\alpha}=\beta-\frac{\delta}{\lambda}(v-\beta)$ for firm one's portion. If $\overline{\alpha}<\alpha$ then firm one will be offered the $\widehat{\alpha}$ contract where $\widehat{\alpha}=\alpha-\frac{\delta}{\lambda}\left[(1-z\theta)(v-\alpha)+(z\theta-\theta_{\min})(\beta-\alpha)\right]$ whilst it will be offered the $\widetilde{\alpha}$ contract, where $\widetilde{\alpha}=\beta-\frac{\delta}{\lambda}\left[v-\beta+(1-z\theta)(v-\alpha)+(z\theta-\theta_{\min})(\beta-\alpha)\right]$, if $\overline{\alpha}>\alpha$. The total cost of the project is either $\psi(\widehat{\alpha})=\lambda\alpha+\theta\beta+\delta(1-\theta_{\min})\alpha+\delta\theta_{\min}\beta$ or $\psi(\widetilde{\alpha})=\lambda\beta+\theta\beta+\delta(1-\theta_{\min})\alpha+\delta\theta_{\min}\beta-\delta(v-\beta)$; these are identical expressions as for when there is complete competition available in the second period. Consequently for the $\widehat{\alpha}$ contract, the optimal split of $\lambda=1-\theta_{\min}$ and $\theta=\theta_{\min}$ makes this cheaper than if there is complete competition (as the first period cost is reduced by $(\overline{\theta}-\theta_{\min})(\beta-\alpha)$ due to firm two having less to produce and firm one more in the first period given their marginal costs). However if the $\widetilde{\alpha}$ contract is offered then the total cost is the same as before meaning any split is possible so long as $\lambda+\theta=1$ and $\lambda>\overline{\lambda}$.

For completeness the case where firm one is unable to produce the whole of the second period project needs to be considered, $\lambda<\overline{\lambda}$ and $\theta>\overline{\theta}$. First assume $1-z\lambda>\theta_{\min}$. In the second period firm one will produce $z\lambda$ for $z\lambda\beta$ whilst firm two will produce the remainder, $1-z\lambda$, for $(1-z\lambda)v$. Firm two is unable to earn this positive profit as it is unable to reject a contract for $\theta\widehat{\beta}$ in the first period where $\widehat{\beta}=\beta-\frac{\delta}{\theta}(1-z\lambda)(v-\beta)$. Overall firm two earns zero profit. Firm one is also unable to earn a profit if $\overline{\alpha}<\alpha$, where $\overline{\alpha}=\beta-\frac{\delta}{\lambda}(v-\beta)$, as it is restricted to the $\widehat{\alpha}$ contract (where $\widehat{\alpha}=\alpha-\delta z(\beta-\alpha)$). If $\overline{\alpha}>\alpha$ then firm one is able to earn a profit from the $\widetilde{\alpha}$ contract, where $\widetilde{\alpha}=\beta-\delta z(\beta-\alpha)-\frac{\delta}{\lambda}(v-\beta)$. The total cost of the project is either $\psi(\widehat{\alpha})=\lambda\alpha+\theta\beta+\delta z\lambda\alpha+\delta(1-z\lambda)\beta$ or $\psi(\widetilde{\alpha})=\lambda\beta+\theta\beta+\delta\beta-\delta z\lambda(v-\alpha)$. As before if the $\widehat{\alpha}$ contract is offered then the cost increases less in λ than in θ . However the cost also increases less in λ than in θ if the $\widetilde{\alpha}$ contract is offered. Thus irrespective of the contract offered the government will increase λ towards $\overline{\lambda}$ and decrease θ towards $\overline{\theta}$ until the regime described previously applies.

The alternative is $1-z\lambda<\theta_{\min}$ when $\lambda<\overline{\lambda}$ and $\theta>\overline{\theta}$. In this case despite firm two only

having to be awarded the minimum level of production in the second period as it is guaranteed this it can charge $\theta_{\min} v$ for it. In the second period firm one will produce the remainder for $(1-\theta_{\min})\beta$. In the first period firm two is unable to earn a positive profit overall meaning it is offered $\theta\widehat{\beta}$ where $\widehat{\beta} = \beta - \frac{\delta\theta_{\min}}{\theta}(v-\beta)$. If $\overline{\alpha} > \alpha$, where $\overline{\alpha} = \beta - \frac{\delta}{\lambda}(1-\theta_{\min})(v-\beta)$, then firm one is restricted to zero profit with $\widehat{\alpha} = \alpha - \frac{\delta}{\lambda}(1-\theta_{\min})(\beta-\alpha)$. If $\overline{\alpha} < \alpha$ then firm one can earn a positive profit with $\widetilde{\alpha} = \beta - \frac{\delta}{\lambda}(1-\theta_{\min})(v-\alpha)$. The total cost of the project is either $\psi(\widehat{\alpha}) = \lambda\alpha + \theta\beta + \delta(1-\theta_{\min})\alpha + \delta\theta_{\min}\beta$ or $\psi(\widetilde{\alpha}) = \lambda\beta + \theta\beta + \delta\beta - \delta(1-\theta_{\min})(v-\alpha)$. As usual if the $\widehat{\alpha}$ contract is offered then a higher λ and lower θ is preferred whilst if the $\widetilde{\alpha}$ contract is offered the first period split makes no difference to the total cost of the project provided $\lambda < \overline{\lambda}$; if $\lambda > \overline{\lambda}$ then the total cost of the project is cheaper.[11]

If rapid expansion is available to firms then it is possible for there to be competition for the whole second period project without excess production in the first period. In some circumstances possessing complete competition for the second period does not cost extra as firm one prices accordingly (via the $\widetilde{\alpha}$ contract.) However if firm one can be restricted to the $\widehat{\alpha}$ contract then the cheapest first and second period split is $\lambda = 1 - \theta_{\min}$ and $\theta = \theta_{\min}$; any other split either decreases λ so work is transferred to the more expensive firm two or λ is increased meaning firm two has to undertake unnecessary work to complete the project (unless it is increased so much that one obtains a monopoly and can charge v for the whole of the second period contract). If firm one has to be offered the $\widetilde{\alpha}$ contract then any first period split costs the same so long as $\lambda + \theta = 1$ and $\lambda > \overline{\lambda}$. As for the limited expansion case there is no benefit to be obtained from ensuring complete second period competition though there is still the benefit derived from firm two being present in the second period as it (now partially) limits the price firm one is able to charge. Likewise government expenditure is no longer as evenly divided between the two periods as v has to be paid for some portions of the second period project meaning the first period cost is lowered but the second period cost rises. This, and the preceding, subsections combine to form the following proposition.

[11] In order for $\lambda > \overline{\lambda}$ to be cheaper requires $\beta + \delta\beta - \delta(1-\theta_{\min})(v-\alpha) > \beta + \delta(1-\theta_{\min})\alpha + \delta\theta_{\min}\beta - \delta(v-\beta)$ which simplifies to $v > \beta$.

Proposition 13 *Ensuring complete competition in the second period will not lower the total cost of the project when there are second period capacity constraints and, in some circumstances, will increase the total project cost.*

5.6 Allocation of rent

The preceding analysis ensures both firms are treated fairly both on and off the equilibrium path. The requirement of treating firms fairly off the equilibrium path gives firm one the opportunity to earn an economic rent. In designing procurement competitions the government has to ensure firms are treated fairly under all scenarios whilst the previous chapter demonstrated the MoD has historically been fair in treating firms when they have wandered off the equilibrium path (for example the AOR procurement). However the possibility of earning an economic rent is not desirable from an economic theory viewpoint; given there is complete information the government should be able to design a procurement mechanism which enables them to capture all the rent. This section prevents such a model, though it relies on treating firms unfairly should they wander off the equilibrium path and therefore there are questions as to whether a government would be able to implement it.

Assume the government follows an alternative procurement mechanism. The government begins by offering firm one a contract for a portion of the first period project. If firm one rejects the contract then a different contract, though for the same proportion, is offered to firm two. If firm two also rejects then firm one is offered their original contract. This continues until one firm accepts the contract they are offered.[12] After firm one's portion of the project has been allocated firm two is offered a contract for its portion of the first period project. If it rejects its contract then firm one is offered the same work for a different price, with the game continuing as before until one firm accepts. The second period proceeds in the same way as the first. As before if one firm undertakes no production in the first period then they are unable to survive into the second period. The firms have no outside options. The government's aim

[12]In reality the price of each contract might have to increase by a small amount between rounds, however this is excluded here to keep a pure strategy equilibrium.

is to offer contracts to each firm whereby the dominant strategy for each firm is to accept. If they reject their contract then, because a different contract is now being offered to the other firm, the other firm might immediately accept meaning the firm that rejected the contract might be forced to leave the industry. Let q_t^i denote the acceptance decision of firm i in period t for its portion of the work whilst $\widehat{q}_t^i$ denotes firm i's acceptance price in period t for firm j's portion of work.

In the second period if only one firm remains then the firm will only accept if the unit price offered is v. Any offer below this will be rejected with the government unable to obtain a better price elsewhere. If two firms remain then firm two will only accept their contract if $q_2^2 \geq \beta$; firm two will only accept the contract if they do not make a loss by undertaking the work. A similar requirement is in place for firm one, namely firm one will only accept a contract for firm two's second period portion if $\widehat{q}_2^2 \geq \alpha$. Firm one will accept a contract for its portion of the project if $q_2^1 \geq \alpha$ whilst firm two will be willing to undertake the work if $\widehat{q}_2^1 \geq \beta$. Thus in the second period so long as a firm's marginal costs of production are covered the firm will accept the contract offered to them by the government knowing that either the other firm will accept the contract or, if they reject, no better offer will be made to them.

In the first period, if firm one has already won its portion of the contract, firm two will only accept their contract if $q_1^2 \geq \beta$. As the firm is unable to earn a second period profit it needs to cover its first period costs. Firm one, however, will now be willing to accept firm two's portion of the contract if $\widehat{q}_1^2 \geq \alpha - \frac{1}{\theta}[\delta(v-\alpha) + \min\{0, (1-\theta)(q_1^1 - \alpha)\}]$; if firm two rejects the contract and firm one subsequently accepts then firm one will, on the equilibrium path, retain any profit already earned. Therefore firm two will be willing to accept the contract so long as it earns normal profits overall. If firm two has already accepted a contract for firm one's portion of the project then firm two will be willing to accept a contract priced at $\widetilde{q}_1^2 \geq \beta - \frac{1}{\theta}[\delta(v-\beta) + \min\{0, (1-\theta)(\widehat{q}_1^1 - \beta)\}]$ for its own portion of the first period project (where $\widetilde{}$ denotes being off the equilibrium path). This price ensures firm two keeps the $(1-\theta)(\widehat{q}_1^1 - \beta)$ profit it has already earned from accepting firm one's portion of the first

period project. If it accepts the contract then it gains a monopoly whilst if it rejects firm one might accept meaning a duopoly in the second period. Firm one will accept this portion of the contract so long as $\widehat{q}_1^1 \geq \alpha$. Firm one will accept its first period contract if $q_1^1 \geq \alpha$ whilst firm two will be willing to undertake the work if $\widehat{q}_1^1 \geq \beta$.

The government, seeking to minimise the total cost of procurement, is able to offer marginal cost contracts to each firm on the equilibrium path. The preceding text shows the dominant strategy for each firm is to accept their contract, otherwise the other firm will accept a contract priced at their marginal cost. If either firm rejects their first period contract then the other firm is offered that portion of work for a price that ensures they earn normal profits over the complete project. Thus the total cost of the projects on the equilibrium path is $(1+\delta)[\alpha + \theta(\beta - \alpha)]$. Thus if the government is prepared to treat firms unfairly off the equilibrium path it can restrict both firms to earning normal profit.

By making these offers there is no necessity for two firms to remain in the second period. The government is able to make an offer for the whole first period project to firm one of $2\alpha - v$. In the second period firm one is able to charge v for the project as firm two no longer survives making the total cost of the project 2α. Thus this mechanism allows the government to obtain the best price overall, though too little is paid in the first period and too much in the second period. If firm one rejects this offer then firm two can be offered $2\beta - v$ in the first period and v in the second period to undertake the project alone. Thus the threat of the other firm being offered the monopoly for a price it would accept forces firm one to accept the monopoly with an overall price equal to the production costs. However the presence of another firm in the second period need not only benefit the price, for example there is the possibility of obtaining a better design if two firms remain or a higher quality product for the same price. There is also a political benefit to the government if it is able to maintain two firms, rather than being seen behind the closure of one.

Note this procurement mechanism relies on threats by the government which are not always credible. Although the government is not modeled as a player of the game, in seeking to protect

its interests it would be likely to intervene and adapt the rules of the game to suit its purpose, as happened when the uninvited sole producer bid for the Type 45s was made. For example, if firm one rejects its first period contract then the rules state the government has to offer a contract to the higher cost firm which, if designed so that firm one accepts its own contract, ensures firm two will accept. Thus the threat to ensure firm one accepts its contract could entail a substantial price increase if firm one leaves the equilibrium path. A more realistic scenario would be that if firm one left the equilibrium path the government would choose to negotiate with firm one to obtain a price between its initial offer and the price it would obtain from firm two. Thus the mechanism lacks credibility off the equilibrium path. In the model in the previous section the government offers each firm a portion of the contract and the prospect of surviving. If a firm views the contract as being unfair then it is for the market to determine the price the contract can obtain. Thus the mechanism has inbuilt credibility by the opportunity to revert to the market when the process strays from the equilibrium path.

5.7 Conclusion

The defence industrial base in the UK, and elsewhere in the world, has been contracting since the early 1990s due to the Cold War peace dividend. The last chapter demonstrated how the MoD responded, or failed to respond, to the changed circumstances in naval procurement. This consolidation, combined with the procurement and naval policy responses by the MoD, has left them facing two companies able to design and build vessels (with a third yard, restricted to building them, currently out of favour for MoD contracts). As competition can no longer be relied upon to deliver the MoD's procurement objectives there is currently a desire to establish a single firm to ensure an effective partnership between them and the MoD will deliver for the future. In other defence product markets there are similar concerns over how an optimal defence industrial policy should operate in the future.

The aim of this chapter was to show an alternative procurement mechanism to competition, with particular emphasis on naval procurement, which acknowledges not only the reduced

options available to the government but also the rational responses by firms. The result is a switch from direct competition for the project to directed buys, with the MoD offering acceptable contracts to each firm for a portion of the project. The dominant strategy for each firm is to accept the contract offered to it otherwise the other firm will accept the same contract causing the firm that rejected their contract to leave the industry. Although competition for the project results in short term efficiency the result can be long-term inefficiency. The directed buy approach offers short-term inefficiency but gains long-term efficiency, due to it being based on maintaining both firms' presence in the second period. Overall the directed buy approach offers a lower cost than can be achieved by direct competition (in the absence of fixed costs). By following this approach the requirement for a defence industrial policy disappears as the optimal industrial structure is a direct result of the cheapest cost of procurement – in most cases the maintenance of some competition in the second period is the foundation upon which the total cost of the project can be lowered.

The analysis in this chapter is based on perfect information. Although integrated project teams (introduced as part of the smart procurement initiative) should lessen the information constraints between industry and the MoD significant disparities remain which means the model needs to be extended to include asymmetric information. Beyond this there are problems with the MoD implementing it – for the mechanism to work requires the MoD to take control of its procurement and have power in its dealings with industry. The last chapter argued that industry currently has more control of MoD procurement than the MoD itself and consequently the MoD has far less power in negotiations. Therefore a shift in the MoD's operation is necessary however it might be forced to undergo this shift as the defence industrial structure evolves in a manner detrimental to the MoD's interests. It would be better if the MoD reviewed its procurement procedures before it is forced to by industry (when it is too late). Whatever approach to procurement the MoD ends up adopting it will eventually have to take a more proactive role in determining the shape of the industrial base to protect its equipment programme (and budget). This paper presents one option available.

Chapter 6

Conclusion

This thesis considers two areas of public policy. The first was concerned with tax competition and policing. When taxes are determined at the local level it is possible for the jurisdictions to levy different taxes and thus influence the location decision of individuals; this consideration does not apply when taxes are determined by the central government. Therefore the pure strategy Nash equilibrium tax is a distorted version of the optimal tax, the distortion being the migration response of the taxpayers to a change in the tax rate at the equilibrium. If the equilibrium migration response is positive, then the equilibrium tax will be higher than optimal whilst it is lower than optimal if the equilibrium migration response is negative. This occurs irrespective of the crime, so long as the aim of the jurisdiction is to maximise the non-locational utility of its taxpayers.

The result of either under- or over-taxation is too little or too many resources devoted to crime fighting. This does provide some benefits, for example if a crime only affects a small minority of the population then a tax can be levied when there is tax competition that would not be levied by a central government. The equilibrium tax can also have some interesting features. The first is the possibility of the tax becoming more distorted as taxpayers become more mobile. Although the expectation would be for taxes to approach the optimum as taxpayers become more mobile, the increase in mobility can increase the magnitude of the equilibrium migration response causing the tax to move further away from the optimum. The second is the central government is able to influence the equilibrium tax through their choice

of the sanction imposed on a criminal if he is caught. It is possible for the government to ensure no distortions occur if taxation is devolved, however this optimal sanction is optimal only from the fiscal viewpoint and is completely independent of the harm caused by the crime.

Given the funding structure of the police in England and Wales, whereby local police authorities are able to impose their own taxes, an empirical investigation was conducted to test whether there was any evidence of tax competition between the police forces. Tests on the best response functions of a simplified version of the model suggested the presence of tax competition between police forces over the last 5 years cannot be ruled out. Therefore the policy implication is the ability to tax, and also to allocate funds between crimes, should not be devolved to local levels of government, rather these powers ought to be retained at the national level. When police force mergers reappear on the political agenda consideration should also be given as to how they are funded.

There is more work yet to be done in this area. The first is to consider non-symmetric equilibria. One of the implicit assumptions of the model is that if both jurisdictions levy the same tax rate then half the taxpayers and half the criminals will reside in each jurisdiction. However there is also the possibility that all taxpayers, for reasons of safety, group in the same jurisdiction. Therefore the question would be whether a devolved tax system can cause ghettoisation. The second area that could benefit from more work is to investigate the effects of devolving the choice of sanction as well as the rate of tax. The final area that needs more work is when there are multiple crimes what happens when the local police force is able to determine their own tax and the allocation of funds between crimes.

The second half of the paper considered the Ministry of Defence's naval procurement programme since the early 1980s. Chapter four argued the Ministry of Defence has been preoccupied with the present and placed no consideration on the future when auctioning naval procurement contracts. Consequently the market determined the industrial structure despite the government being the major purchaser of its products. Whilst market interests should ensure short term efficiency it is possible for the market to develop in a manner to the cus-

tomer's detriment. The unfettered pursuit of competition led to the Ministry of Defence not possessing a defence industrial policy and therefore exposed to whatever the market provided. Due to a lack of orders some firms left the industry. The Ministry of Defence stated that this did not cause any loss of competition, rather it was beneficial as the overheads of yards excess to requirement no longer had to be met. An empirical investigation into the price paid for warship hulls suggests this is valid, however the data series ended in financial year 2000 when the lack of care previously given to the industrial base started to cause the Ministry of Defence problems. Additionally the Ministry of Defence benefitted from the misspecification of yards at privatisation and the lack of orders after the conclusion of the Cold War.

At the start of the millennium the lack of care given to the industrial base caused problems for the Ministry of Defence as it sought to enlarge its procurement programme (initially with the Type 45 programme and then with the CVF). As a result there was a shift away from competition towards partnership despite the relationship between the Ministry of Defence and the defence companies exhibiting very little trust. Furthermore, difficulties between the companies are preventing them from merging. Although this is a desire of the Ministry of Defence and they control contracts, in essence whether or not a yard survives, they still refuse to intervene in the defence industrial base and mold it to a shape they desire. The Ministry of Defence needs to overcome its reluctance to intervene in the market in order to protect its long term interests.

Chapter five presented a model which demonstrated the benefits there could be (in terms of reduced prices) if a short term inefficiency (a higher price) is experienced. The mechanism requires the Ministry of Defence to shift to a system of allocated buys, offering each firm a portion of the contract for a price which the firm will accept (as the equilibrium path is based on accepting being the dominant strategy for each firm). The presence of competition in the second period overcomes difficulties associated with the enforcement of contracts. The model therefore suggests maintaining a duopoly has benefits compared to allowing a monopoly.

There is more work to be done on the effects of not considering future projects when

procuring a vessel. The data series concluded before the start of the Type 45 and CVF programmes and once these are completed it will be interesting to investigate whether the closure of yards in the 1990s has had any effect on the final price of the projects. There are also a number of ways in which the model can be developed. The model be rerun but with asymmetric information regarding firms' costs (incase the integrated project teams do not know the true costs or the open book accounting in the partnership does not occur). Further the question of whether there is a role for public owned production also needs investigating. Although the Ministry of Defence has no desire to undertake production (and the model assumed either that it did not want to or would possess higher variable costs than β) the possibility of a return to state production ought to be considered.

This thesis has aimed to apply microeconomics to two issues that someone in government ought to be considering. There is more work to be done on both topics, however this thesis provides a base from which to start.

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