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A SOVIET QUASI-MARKET FOR INVENTIONS: JET PROPULSION, 1932 TO 1946*

Mark Harrison**

Abstract

This paper is about how a command system allocated resources under profound uncertainty. The command system was the Soviet economy, the period was Stalin's dictatorship, and the resources were designated for military research & development. The context was formed by the limits of the existing aviation propulsion technology, the need to replace it with another, and uncertainty as to how to do so. We observe the formation of a quasi-market in which rival agents proposed projects and competed for funding to carry them out. We find rivalry and rent seeking, imperfectly regulated by principals. As rent seeking spread and uncertainty was reduced the quasi-market was closed down and replaced by strict hierarchical allocation and monitoring. In theory a dictator cannot commit to refrain from taxing the returns from today's effort tomorrow; therefore, we expect agents in a command system to seek only short term returns from quasi-market activity. Agents' willingness to invest in the Soviet quasi-market for inventions is ascribed to a reputation mechanism that enforced long-run returns.

JEL Codes: L22, N74, O31, P26.

Keywords: command economy, credible commitment, decentralization, incentives, invention, jet propulsion, quasi-market, Soviet Union, technology transfer, reputation.

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** Mail: Department of Economics, University of Warwick, Coventry CV4 7AL, UK. E-mail: mark.harrison@warwick.ac.uk

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A SOVIET QUASI-MARKET FOR INVENTIONS: JET PROPULSION, 1932 TO 1946

Introduction

This paper is about an artificial market within a centralized command economy. It is generally thought that markets allocate resources more efficiently than hierarchies when information is dispersed and there is no easy way of making bureaucrats pay for mistakes: in other words, in most circumstances (Hayek, 1945).[1] But when political and economic power is already concentrated in the hands of an authoritarian ruler there is also no easy way for society to promise him compensation in return for surrendering power (Acemoglu, Robinson, 2000). In this case excessive hierarchy is likely to persist and society will continue to lose from it. Beyond a point, however, the losses may detract from the income not just of society but also of the ruler. In that case, why should the ruler not gain by selective delegation to others of those decisions that he is least equipped to make efficiently?

From the early 1930s Soviet officials began to discuss whether it was possible to nest the informational and incentive advantages of markets within the hierarchical structures of the command economy behind closed doors (Davies, 1996, pp. 201-28). From the 1960s they pursued this quest openly under the banner of socialist economic "reforms." These reforms aimed to devolve use rights over selected assets to selected agents who would be converted from hierarchical subordinates into financially independent stakeholders, and from rent-sharers to profit-makers. Give a clearer interest in the results of their own efforts, they would be motivated to achieve the leaders' objectives at lower cost as a result.

The reforms were ultimately a failure, however. The literature understands this as the result of a dynamic commitment weakness. From one point of view it is about taxation. Litwack (1991) describes the problem as the inability of Soviet planners to commit to a long term scheme to tax the results of initiative; rather, the tax on tomorrow's productivity is determined only after observing that of today. As a result, today's effort goes into negotiating tomorrow's taxes, not improving productivity. From another point of view selective delegation is not sustainable in the long run. Williamson (1996, p. 17) considers the problem of "credible selective intervention" where intervention is the opposite of delegation: a ruler who is in a position to intervene selectively, i.e. at some particular point, cannot commit not to intervene at any point. If a hierarchical principal were able to commit to a policy of hands-off when decentralization yields the first-best outcome, and to intervene only when the market outcome was second-best, then socialist planning could have the best of everything. But it cannot.

Up to this point the problem is framed in terms of control over streams of expected future taxes on and rewards to effort. Control over future income streams is also an aspect of property rights. For subordinate agents to become autonomous stakeholders, and to change from rent-sharing to profit-making, they must seize their stake and acquire irrevocable disposal rights over it. As long as their control over assets remained at the discretion of the ruler, they would rationally fear future expropriation. By the same token

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the ruler, as long as he stood above the law, could not bind himself not to take back his assets and the profits earned on them in the future (Williamson, 1996, p. 113). He had specific production objectives for the sake of which he remained willing to override his own previous decision to delegate. The use rights that he delegated could only be temporary in principle, even if continually extended in practice. Consequently agents who were granted these temporary rights continued to seek to share the rents generated in the command system rather than make profits from production. Moreover, they could exploit these rights to extract a rent from the dictator up to the level of the cost saving that he aimed to achieve by decentralizing.

At first sight this seems to imply that selective delegation can never work. Yet, sometimes it does. One area where it seems to have worked was in the invention phase of Soviet military research and development. The invention phase was marked by technological uncertainty and information bias: while nobody yet knew the answers, the specialists knew the problems better than the officials who funded them. Under these conditions inventive activity could not be regimented from above. Instead, rival inventors competed for funding and rewards (Holloway, 1982a, pp. 317-19). Decentralization seems to have worked in the sense that Soviet designers did keep pace with the global technological frontier as it expanded and did occasionally expand it themselves. The results included high-quality tanks and aircraft, atomic weapons and intercontinental missiles, satellites in space, and a remotely guided vehicle on the surface of the moon. In short, the Soviet command system could apparently solve some problems through selective delegation even though permanent disposal rights over assets were not devolved and future taxes remained undetermined. An empirical question then arises: what mechanism made selective decentralization work in this specific context?

The present paper is a study of decentralization in the Soviet command system. I consider the process that led to a new aerospace technology based on jet propulsion. The period is the Stalin era, before decentralizing "reforms" became fashionable; I begin at the dawn of the process in 1932 and I conclude in 1946 when the invention phase had come to an end. Throughout this period there existed an artificial "quasi-market" for inventions. The problem of high-speed, high-altitude aviation was placed in this quasi-market at the beginning of the 1930s when uncertainties and information biases were at their greatest. The problem was removed from the quasi-market and returned to direct hierarchical regulation between 1944 and 1946 when the concept had been implemented and the uncertainties removed.

I explore this topic on the basis of the recently declassified records of the defence industry held by the Russian State Economics Archive (RGAE), supplemented by those of the Red Army held by the Russian State Military Archive (RGVA), and a few records from the State Archive of the Russian Federation (GARF), all in Moscow. These are supplemented by available memoirs and a wide secondary literature that narrates the stories of lives and deeds. The official documents are marked, however, by qualities that the available narratives tend to lack: they are written without hindsight, and they are not selected to tell a story with an uplifting moral or to show someone in a good or bad light. Of course, they are selective in other ways. For present purposes the archives make it possible to do something that is new: to describe the Soviet market for inventions as an economic institution, and analyse the conditions for it to succeed.

A note on Soviet terminology seems inescapable. Soviet ministries were called "people's commissariats" until they were renamed ministries in 1946. I call them ministries throughout. I generally refer to the USSR Council of People's Commissars (Ministers) as "the government," and its chairman as the prime minister. Where necessary I use Russian official acronyms as follows:

KB, OKB:	Design Bureau, Experimental Design Bureau
NII:	Scientific Research Institute
NKVD (MVD):	People's Commissariat (Ministry) of Internal Affairs

It may also help to know of the major reorganizations of industrial ministries in the late 1930s: in December 1936 the ministry of heavy industry was split among several specialized branches of which one was the defence industry; two years later, in January 1939 the ministry of the defence industry was itself split into new ministries of the aircraft, ammunition, armament, and shipbuilding industries.

The paper is organized as follows. Much of it is description. Section A sets out the technological problem that confronted the Soviet economy. Section B evaluates the scale and scope of the effort invested in solving it. Section C discusses the nature of quasi-markets and describes the structure of the quasi-market for inventions within the framework of a command system in terms of principals and agents. Section D illustrates the role of the agents in forming the market, entering it, and securing initial funding. Section E looks at the interplay between principals and agents when projects came up for refinancing. How did principals intervene in the market? To what extent did agents' competition limit or embody rent seeking? Section F shows that the quasi-market for inventions gave rise to an informal secondary market in long-lived research assets. As Section G briefly recounts, once the technological uncertainties had been removed, the authorities closed the quasi-market for inventions down. Section H returns to analysis of the problem posed in the introduction, that of credible selective delegation: how was successful invention motivated in this temporary market, and how could agents enforce their payoffs for success? A final section concludes.

A. The Problem of Jet Propulsion

In the interwar period, the airscrew propeller driven by a reciprocating piston engine reached its limits in terms of speed and altitude of aircraft performance (Grigor´ev, 1994, p. 189). This prompted intensive efforts in several countries to develop new types of aeroengine based on a continuous thermal cycle. Some efforts succeeded and others failed. The success story was that of jet propulsion. The parallel story of the aviation steam turbine described by Harrison (2003a) is also of interest but ended in failure.

Jet propulsion or reaction is the principle underlying both rocket motors and jet engines: action and reaction are equal and opposite. A rocket is a jet that does not need to breathe air. Small solid-fuelled rockets had been used for hundreds of years in many countries for display and signals. A survey prepared in the USSR ministry for ammunition in 1939 reminds us that rockets were used for the first time in European warfare in the Napoleonic wars as an incendiary siege weapon and later as ammunition against troops; by the middle of the nineteenth century most armies carried substantial stocks of rocket artillery.[2] As a result of improvements in conventional artillery rockets were little used in World War I, but interest in them revived in the interwar period in connection with new fuels and artillery uses. Accompanying developments in aviation played a role because rockets could be used for both air-to-surface and surface-to-air artillery.

In the 1930s rockets also began to be used in a new way as aviation boosters. Since rocket fuel contained its own combustion ingredients, rockets were capable of performing at limitless altitudes but for limited duration. To create a primary aviation power plant therefore required a rocket motor of unprecedented size and complexity, using more powerful liquid fuels with pressurized or pumped fuel delivery; in turn these required substantial advances in material and fuel sciences and control systems. In the interwar years it was unclear whether a rocket aircraft would ever be practicable.

The air-breathing jet engine was a more recent concept. The simplest version was a hollow tube or ramjet; when the tube was moving at high speed air would enter it at one end and be compressed, mixed with fuel, and burnt; the exhaust gases left the other end in a jet stream that drove the tube forward. The ramjet was no good as a primary power plant because something else had to accelerate it to high speed before ignition. Thus a primary power plant had to be able to suck in and compress air when stationary. In Frank Whittle's patent of 1930 this need was met by a supercharger or compressor attached to a turbine driven by the exhaust gases; hence turbojet.

In the 1930s theorizing ran far ahead of practice. In theory jets were capable of higher speeds at higher altitudes than airscrew engines, though not of space flight, and for much longer duration than rockets. The theory of the gas turbine was also not a problem; it arose naturally from existing applications of steam turbines, principally in electricity generation and marine engineering (Voronkov, 1984, p. 115). The other major concepts that would power military and commercial aircraft for the next half century were also worked out at this time. For example, the thermodynamic efficiency of the turbojet was already understood to be poor at low speeds and altitudes, so designers were already thinking about a turboprop in which the gas turbine would drive both the compressor and reduction gears linked to an airscrew for slower long-range aircraft. Between the turbojet and turboprop lay the turbofan or turbojet engine with a bypass chamber, universally applied in modern jet airliners; a bypass engine was patented by the Soviet turbojet designer Arkhip Liul´ka in April 1941 (Liul´ka and Kuvshinnikov, 1981, p. 91).

To put a gas turbine into a jet engine in practice, however, raised requirements on material and fuel sciences and control systems that were far above the level of the time. In the interwar years no one knew for sure that a turbojet could be made to work. If anything it looked further from realization than the idea of a rocket aircraft.

Expectations, positive and negative, were very important. In each country faith in the future of the turbojet was reinforced by the belief that rivals in other countries were making equal or greater efforts. These beliefs helped to make the turbojet a reality and in this sense (MacKenzie, 1996, p. 57) it was a self-fulfilling prophecy. But there were many failures *en route*; these were double-edged. In the long run the failures were positive: they promoted learning and were a necessary cost of ultimate success. In the short run, however, the setbacks were just that; they set the process back and fuelled scepticism and conservatism as even committed believers understood. As an investigation into faulty parts for a Soviet prototype gas turbine reported in 1938: "to start the engine in the form produced by the factory − if it were possible − could only end in an accident *and destroy the idea* of building a gas turbine at its very inception."[3] In Britain Frank Whittle

(1953, p. 78) feared that each mishap would destroy his sponsors' faith in himself and his engine.

Scepticism was an obstacle everywhere. According to Liul´ka disbelief persisted in the Soviet Union until the end of 1943 (Liul´ka, Kuvshinnikov, 1981, p. 89). In the United States in June 1940 the National Academy of Sciences announced that the turbojet was technically infeasible; a passage from its report reproduced by Golley (1987, facing page 114) bears Whittle's handwritten comment: "Good thing I was too stupid to know this." Actually a Heinkel turbojet aircraft had already flown in secret in Germany the year *before* the American report. Even in Germany, as the inventor Hans von Ohain and the BMW engineer Peter Kappus recalled independently (Ermenc, 1990, pp. 8, 89), the scepticism evaporated only after the principle had been demonstrated in flight. But it may be that inventors also puffed up their reputations by stressing the resistance they had had to overcome.

A natural response to the great gap between theory and practice was to compromise. To get around the fundamental difficulty of the turbocompressor, clever and inventive people all over Europe were exploring a variety of intermediate steps and hybrid solutions; the Soviet Union was perhaps unusual in the number of alternatives that were pursued simultaneously (Egorov, 1994, pp. 424-36; Serov, 1997; Gordon, Dexter, 1999).

The simplest stopgap was to strap auxiliary ramjet boosters onto an otherwise conventional aircraft, but there was little practical gain because the boosters did not add much speed and caused large aerodynamic losses. A more advanced compromise was to use an auxiliary piston engine to supercharge a jet engine. This hybrid engine resulted in a primary power plant that was less demanding than the turbojet because the elements were all established technologies; Whittle (1953, p. 39) filed a patent for such an engine in the early 1930s. There was also interest in refining the existing steam turbine technology to drive a conventional airscrew more cheaply and reliably (Harrison, 2003a): if oil-fired steam turbines had replaced the reciprocating engine at sea, why not in the air as well?

Finally there was still rocketry: if the turbojet turned out to be impractical, then rocket motors must be developed far beyond their existing limits. Thinking along this line remained influential even after the turbojet had become a proven concept. For example, concluding a long report to Stalin's deputy Malenkov in July 1944, minister of the aircraft industry Shakhurin compared the respective potentials of jet and rocket aviation as follows:

> Aircraft with motors of the liquid-fuelled [rocket] type have a bigger future in terms of achieving greater efficiency [a larger KPD, coefficient of useful action] and a sharp increase in the tactical flight characteristics of jet-propelled devices. The power of such a motor does not depend on altitude and it can operate (even better) in airless space. However, extremely high fuel expenditures at the present stage of their development (cf the Me[sserschmitt]-163) sharply limit the great potential of this type of aircraft. This is why existing jet-propelled aircraft have big engines of the air[-jet] type.[4]

From a mission standpoint, what were the appropriate responses to the extent of technological uncertainty? The best chances of progress would result from an open-ended commitment to advance on many fronts at the same time. Many problems demanded simultaneous technological solutions. Many applications would not be detected without free-ranging exploration of new technologies. The state needed to fund many projects, accepting a high probability of failure in any one of them, in order to ensure that at least some successful projects would be included. As Joel Mokyr (1990, pp. 176-7) has taught us, many failures could be expected as part of the cost of success.

As far as the scale of effort is concerned, no government would accept a completely open financial commitment, but there were different degrees of open-handedness across countries. For each country the feasibility of a given commitment varied with economic size, development level, and mobilization capacity. The interwar British, German, and Soviet economies were of about the same size in GDP. Britain and Germany were more developed in science and industry than the USSR; the Soviet economy could claim an advantage, however, in its superior mobilization capacity (Harrison, 1998).

B. Scale and Scope

This section gives a brief account of the scale and scope of jet propulsion research for aviation in the Soviet Union from 1932 to 1946. Table 1 lists eighteen major projects over the period; the research in rocketry, limited to aviation-related activities, excludes numerous artillery projects some of which were highly successful. It is compiled mainly from items reported in the plans, reports, and memoranda of the ministries of defence, internal affairs, and the heavy, defence, ammunition, and aircraft industries; these are listed more fully in the Appendix.

TABLE 1 ABOUT HERE.

The "major project" as a unit of measure is convenient but simplified or fuzzy in some dimensions. First, research strategies varied; for example Glushko, Merkulov, and Uvarov were often to be found engaged in multiple designs for power plants of varying size and capacity based on similar principles at the same time, whereas Liul´ka committed everything to a single design that evolved through time. To make sense of the data I have counted the work of each as a single major project, and this has imposed some aggregation on the "minor" ones. (But I have made an exception for Glushko whose collaboration with Sergei Korolev on a rocket aircraft in 1936 and 1937 was clearly different from his other projects in scale and significance.)

Second, the official documents do not capture the informal or peripheral involvement of designers before they moved to the centre of the field. The documents must also fail to reflect the disruption or continuity in designers' work as they moved from one organization to another. It is not clear, for example, what Uvarov did in 1940 or whether, when he left VTI in 1939 and reappeared at TsIAM in 1941, he brought with him his assistants and equipment or only his personal intellectual capital.

The great advantage of Table 1 is that the data underlying it were created without foresight. In contrast the memoirs and biographies of the designers such as Liul´ka and Uvarov who were eventually successful naturally pay scant attention to the projects of their lesser rivals. This makes the table substantially more complete than previous narrative accounts.

Table 1 shows six major projects in aviation rocketry and twelve in jet aviation over the period, but this does not give a clear impression of relative importance since some projects were long-lived while others appeared and disappeared within a year. Figure 1 measures the overall investment in cumulative "major project-years." It shows that until 1937 research in rocketry and jet engines advanced more or less in step; after that, the balance shifted away from rocketry and by 1946 jet engine development had accomplished almost two thirds of the 76 project years accumulated in total.

FIGURE 1 ABOUT HERE.

Also of interest is the turnover of projects, especially the termination of those regarded as unsuccessful. Figure 2 illustrates this for the aviation field as a whole. It shows clearly the buildup of research and design activity in the second half of the 1930s. It shows that project closures were concentrated in 1937 to 1939, and in the first two and a half years of the war. Closer inspection of Table 1 reveals that there was a complete break in rocketry development at the end of 1938, when all projects then current were terminated. Finally, 1946 was the first year in a decade and a half when no projects were closed down and no new ones were begun.

FIGURE 2 ABOUT HERE.

Table 1 showed that some fifteen distinct research establishments were involved in developing jet propulsion for aviation; these are detailed in Table 2. The true total of establishments listed in the table is less than appears in the table because there were many reorganizations and changes of name, usually driven by a desire to break with the errors of the past. Behind these are a strife-torn story of the fall and rise of the idea of jet-propelled aviation. The central organization in this story was the Jet Propulsion Research Institute (RNII) formed in 1934. Its turbulent history has been described recently by Harrison (2000, pp. 127-30) and Siddiqi (2000, pp. 1-14). The low point fell between 1937 and the second half of 1941. In 1937, discredited by association with "enemies of the people" charged with wasting state funds on useless dreams of rocket-powered flight, RNII was converted into NII-3, an adjunct of the ammunition industry, and ordered to concentrate on designing rocket shells and mortars. Interest in rocket aviation was revived in August 1941 and in jet engines in July 1942. NII-3 was converted at first to a State Institute for Jet Propulsion Technology (GIRT) reporting directly to the central government. It was fully rehabilitated in the spring of 1944 as the Research Institute for Jet-Propelled Aviation (NIIRA) and then Research Institute no. 1 (NII-1) of the aviation industry. Its many transformations are shown for reference in Figure 3.

TABLE 2 ABOUT HERE.

FIGURE 3 ABOUT HERE.

The organizations involved were of modest size. Table 3 shows that RNII-NII-3 had 400 or so staff in the mid-1930s of whom around one quarter could be classed as specialist "engineering and technical employees." By the end of the decade this number had risen to more than 800. In the same period the RNII budget trebled, although not all of this was real growth; price and wage inflation was especially rapid between 1937 and 1940 (Bergson, 1961, pp. 367-8, 422). In comparison with other establishments of a similar profile, RNII-NII-3 was medium-sized; the other main rocketry establishment, KB-7 was much smaller. This is shown by Table 4 which compares them with other research outfits of the ammunition industry in 1938.

TABLE 3 ABOUT HERE.

TABLE 4 ABOUT HERE.

In considering these figures it is important to bear in mind that most of the work done in RNII-NII-3 and KB-7 was concerned with rocket artillery, not aviation. Aviation projects accounted for two fifths of the value of research and experimentation planned by RNII in 1937.[5] By 1940 their nominal value had fallen absolutely, while their share in the much larger NII-3 budget was now only 6 per cent.[6]

These research expenditures were a very small fraction of overall defence procurement. In the late 1930s they ran at less than a million rubles a year. Equipment orders for the army and navy in 1937 were 5.7 *billion* rubles (Davies, Harrison, 1997), and 14.5 billion rubles for the army alone in 1940 (Harrison, 1996, p. 281).

The Soviet outlays appear trivial in comparison with the resources that Germany devoted to the development of V-weapons. A postwar American estimate puts the total development costs of the jet-powered V-1 cruise missile to Germany at approximately $200 million in wartime US prices, and those of the V-2 rocket at ten times that amount, about the same as the $2 billion cost of the Manhattan Project (Ordway, Sharpe, 1979, pp. 242, 253). Given that one prewar ruble was worth 35 US wartime cents at most (Harrison, 1996, 275) the resources invested in Soviet aviation jet propulsion in the 1930s and 1940s can hardly have totalled more than $10 million.

C. Dictator, Army, and Industry in a Quasi-Market

In this section I discuss the differences between "real" and quasi-markets and provide a simplified description of the structure of the market for inventions. We think of real markets as formed by buyers and sellers who enter the market independently, motivated by their own self-interest. In real markets prices are set by interpersonal negotiation or impersonal bidding, or are preset by one side in the presence of market power. At least one equilibrium is possible and the interaction of supply and demand generally leads to it. Contract disputes are resolved by custom or law. In the outcome, the market steers resources in the general direction of their most profitable use.

Quasi-markets, in contrast, are created by the state to allow its own agents to engage in decentralized transactions with each other. The agents enter the quasi-markets because they are told to. They are not supposed to behave in an independently self-interested way but to follow contingent rules. If they find themselves in dispute, the principal determines whether or not to intervene and which side to uphold. Prices and incentives in quasi-markets are formed by the principal's decision; the process is not equilibrating and adjustment typically involves "false" or cross-trading, described by Morishima (1984, p. 15). The principal usually tries to calibrate incentives in advance so when his agents allocate resources in detail the results will conform to broad limits already set out in centralized plans.

The idea of quasi-markets is widely applied to describe decentralized allocation within large private and public-sector organizations, for example the British welfare state since Margaret Thatcher (Le Grand, 1991; le Grand and Bartlett, 1993; Bartlett, Roberts, and le Grand, 1998). Its conceptual origins, however, lie with Ludwig von Mises (1949/1998, pp. 701-706), who employed the term to describe the market-like rules for decentralized allocation that contemporary socialists such as Oskar Lange wanted to embed within a planned economy. Mises regarded the idea as inherently unworkable; he argued that, since the agents would have no property of their own to lose, quasi-markets would be dominated by the "audacity, carelessness, and unreasonable optimism" of "the least scrupulous visionaries or scoundrels." We shall find that, while he had an element of prophetic truth of his side, the reality of the quasi-market for inventions was much more complex and interesting than this would suggest. In particular, the quasi-market began to blur into a real market at two points: the sellers played a significant role in influencing the principal to create it; and enforcement relied significantly on a reputation mechanism that was independent of the principal.

The structure of the market was roughly as follows. There were four main categories of player and Figure 4 illustrates the quadrilateral relationships among them. Stalin, the *dictator*, was personally represented by central government. On Stalin's behalf, high-level government agencies established the framework within which the other players operated by issuing strategic directives from time to time. Formally these were usually the government subcommittee responsible for defence matters or, in wartime the war cabinet. In reality, regardless of formal authority, Stalin decided many of these things personally in consultation with a varying circle of members of the party politburo, usually after receiving representations from other stakeholders (Khlevniuk et al., 1995; Khlevniuk, 1996). Examples of the major directives affecting R&D for jet propulsion during the period under review are shown in Table 5.

FIGURE 4 ABOUT HERE.

TABLE 5 ABOUT HERE.

The actors at the next level down were the defence agencies to whom Stalin delegated the power to fund research, and the specialized fundholders or suppliers of R&D services. The defence ministry was the prospective purchaser of jet propulsion technology and acted as the *funding agency*.The funder commissioned R&D services from the fundholder who was paid to supply them. The funder's contract could implement a government decree using centralized funds earmarked from the USSR state budget. Alternatively, as a budgetary institution the defence ministry could enter into decentralized contracts with industrial institutes and design bureaux for R&D services on its own initiative.

The *fundholder* was the legal owner of the R&D organization. The main fundholders supplying jet propulsion research are listed above in Table 2. If the list appears complex at first sight, the detail can be simplified by grasping the three main types of fundholder, indexed in the table as **A** for Army, **D** for Dictator, or **I** for Industry. The "normal" arrangement of the quasi-market for inventions was that **Industry**, i.e. the ministry of heavy industry and its successors responsible for the various branches of the defence industry, in particular the aircraft and ammunition industries, was the fundholder. But other industrial interests could also take on sideline responsibilities, for example the electricity generation industry. In varying circumstances the **Army** and the **Dictator** intervened. As the principal funder the Red Army made various attempts to by-pass the quasi-market for inventions and substitute itself for industry as the fundholder by establishing its own in-house jet propulsion research and development facilities, for example KB-7. In Figure 3 this is shown by the fine dashed arrow. Second, Stalin's NKVD sometimes acted directly for him by substituting itself for the fundholder, seizing R&D personnel and assets and managing them on a prison basis in a *sharaga* or *sharashka* (Albrecht, 1989, pp. 133-5; Starkov, 2000, pp. 255-60); this is indicated by the heavy dashed arrow. The fundholder of factory no. 16 in Kazan´, for example, was the ministry for the aircraft industry, but its aeroengine design bureau was a *sharaga* staffed by prisoners and run by the NKVD fourth special department.

Normally, however, funding departments and fundholders formulated independent operational plans that were then coordinated through a contracting process. The most important planning horizon was annual. The Red Army had an annual plan for the development of military inventions most of which it contracted out to other organizations through the quasi-market for inventions. Industrial ministries also had their own R&D plans, for example the annual plan for aeroengine research and experimentation to be carried out by the institutes and bureaux of the aviation industry, part of which was made up by contracts accepted from the Red Army. But some R&D was also financed by industry.

The point is illustrated by the sources of funding of a design organization such as NII-3. Table 6 shows that NII-3 planned to undertake 11,725 thousand rubles of expenditure on research in 1940. This sum was to come from three sources, one part from the state budget, another from decentralized contracts with outside funding departments, mainly the Red Army, and the rest from the NII-3 fundholder, the responsible chief administration in the ministry of the ammunition industry.

TABLE 6 ABOUT HERE.

These arrangements imposed the following structure on competition among designers. There were many designers and many design organizations. Since R&D projects had to fall under one or another design organization, the design organization was the main vehicle for this competition. Designers competed for funding from a limited number of sources. In principle the defence industry, later the aviation industry, was the monopoly fundholder but in practice its monopoly was limited and threatened by other parties: industries with sideline interests in potential diversification, military men interested in the scope for vertical integration, and the dictator who could revoke the delegation of his powers to industry at any time and impose direct control under the NKVD.

D. Action and Reaction

The quasi-market for inventions was not atomistic or impersonal. Rather, it was driven by the designers. David Holloway (1982a, p. 288) has suggested that the balance between supply-side or “discovery-push” factors and “demand-pull” factors determined how major innovations were diffused through the Soviet defence sector. The stereotype of a command economy might lead one to expect that the active side of the market was the demand side in the sense that the funding principal issued compulsory contracts on the basis of a high-level plan, and the fundholders then complied with the contracts. The difficulty with this stereotype is that, given the technological uncertainty surrounding the future of aviation in the 1930s, the principal did not know what contracts to offer. The specialist agents on the supply side knew the answers better than the principal, and the command system had to adapt to this reality. Thus the active side of the market was the supply side and decision making on the demand side was mainly reactive.

In this section I describe briefly the supply-side activity, which took the form of proposals for funding from three groups of actors: established designers, backyard inventors, and foreign specialists. I note separately the uses that these proposals made of information from the foreign press and foreign commercial information.

The reactive character of decision making on the demand side is shown by the character of funding decisions: reports and resolutions that consolidated or cancelled existing rival projects greatly outweighed the number of decisions that authorized new ones. Designers' control of the initiative resulted in a tendency for projects to proliferate that the funding principals found difficult to control. We will look more closely at this in Part 5. But the scope of the designers' initiative went beyond this; it was not just that they held the initiative within the market. They also helped to create it. In this sense the distinction between real and quasi-markets was not completely watertight.

1. Established Designers

How did projects win a place in the plan? There was a variety of routes, but in each case the initiative lay with the designer. This was not a process whereby all-seeing and all-knowing planners identified needs from above, sought out designers, and put them together with resources to meet the needs identified. Rather, proposals came first from below. As minister of the aircraft industry Shakhurin explained to deputy prime minister Voznesenskii in February 1941, "Work on the creation of jet propulsion engines at home in the USSR […] began on the initiative of a few engineers taking the form of inventors' proposals."[7] This was the case in other defence projects too, for example the first movers were the designers in both the failed attempt to build an aviation power plant around a steam turbine (Harrison, 2003a) and the successful project to build a Soviet atomic bomb (Holloway, 1994, pp. 72-95).

Liul´ka, father of the Soviet turbojet, began his work in 1936 on the back of a steam turbine project at the Khar´kov Aviation Institute (Egorov, Sultanov); this experience soon convinced him that steam power had no future in aviation. The following account is based on Berne and Perov (1998, pp. 78-81). Liul´ka wanted to develop work on a turbojet but his path was strewn with obstacles. His superiors in the Khar´kov institute refused to back his work directly and referred him to Moscow. There he met Uvarov who helped him get some funding from the aviation industry. But money opened few doors without adequate technical support; back in Khar´kov his project languished. In 1938 Liul´ka contrived "with great difficulty" to meet minister for the defence industry Mikhail Kaganovich who was impressed enough to convene a night-time meeting with his deputies; the outcome was to offer Liul´ka the facilities of SKB-1 at the Leningrad Kirov factory. Back in Khar´kov Liul´ka began to build a new engine with an axial compressor in the expectation of air force sponsorship. When this failed to materialize he wrote to prime minister Viacheslav Molotov in March 1939. At the end of this year he finally secured proper funding from the aviation industry and a proper base at the Central Boiler and Turbine Institute (TsKTI) of the electrical industry (see Table 1). During 1940 and 1941 Liul´ka designed an engine and experimented with its turbine, compressor, and combustion chamber. However, within a few days of the outbreak of the war this work was mothballed in favor of an alternative plan to build a liquid-fuelled rocket fighter, the BI, pursued to a catastrophic conclusion in early 1943.

Designers worked to secure ministerial approval and the funding that followed. If refused at one level, they appealed to the next. If necessary they began work without waiting for authorization; they illegally diverted resources of their own design organizations that had been allocated to other uses and then used the preliminary results to support subsequent attempts to gain official backing. The principle is illustrated by an anecdote (Perakh, 1998, §9.1): in the 1930s a group of young scientists who wanted to embark on research in atomic physics approached A.F. Ioffe, director of the famous Fiztekh, the Institute of Physics and Technology in Leningrad. Ioffe saw the potential of their proposal but was under pressure from above to give more resources to applied research instead. He realized it might be difficult to justify the proposal to the party authorities, and resolved to go ahead by means of a ruse. He gave laboratory space to the atomic physics project on an unofficial basis, and posted a sign on the door: "Stockroom." As he expected, at the next inspection the party officials walked straight past without curiosity. The project was safe until the time came for Stalin to recognize the importance of atomic physics.

Such behavior caused projects to proliferate in an uncontrolled way. The consequences were outlined by NII-3 director A.G. Kostikov at an internal meeting in May 1942 when the strain on resources was at its most intense:[8]

> As an example of how we are forced to diffuse the attention of our cadres I will take the first research department. There are 26 [research] topics for 10 engineers. Some of these topics are incidental to our institute and do not match its profile or specialization. These topics arose because there were people to put them forward and instead of passing them on to those organizations for whom such topics were more appropriate we engaged in them ourselves. […] It's characteristic of such topics that working on them involves unnecessary investigations since [we have] no corresponding experience. Often what is done is done many times, and all because we took on what was not our business, because we have neither experience nor cadres to work on items that don't match the profile of our institute.

Successful proposals required investments in lobbying. Such investments could bring the designer not only success with an individual proposal but also a privileged long-term relationship with the government officials responsible for funding. To win support for their projects and adoption of their designs, designers had to be "heterogeneous engineers" capable of reshaping organizational as well as technological constraints (MacKenzie, 1996, p. 13). To create a demand for new designs they had to build coalitions with soldiers or industrialists to overcome interests vested in markets for products that already existed (Holloway, 1982a, p. 292). In particular, they had to overcome the preference of industry for the undisturbed mass production of weapons in long serial runs, which was often at odds with radical product innovation and the risks and requirements of continual upheaval in production (Berliner, 1976, pp. 534-8; Albrecht, 1989, pp. 195-7, 207-8). This could make it difficult to establish where the initiative lay and blurred the whole distinction between discovery-push and demand-pull. It also provides an exception to the rule that Soviet producers did not need to hire marketing agents, only supply facilitators or *tolkachi*.

The aircraft designer Sukhoi, for example, is said to have won success in having his designs adopted only after he took on a partner, E.A. Ivanov, who had the political and bureaucratic skills to push his product through the military and party-state apparatus (Ozerov, 1973, p. 53). Almquist (1990, pp. 70-3) has described the political "connectedness" of successful postwar Soviet designers. The German turbojet pioneer Hans von Ohain prospered on account of the alliance he forged with the aircraft manufacturer Otto Heinkel; according to Kappus (Ermenc, 1990, p. 91) the support of Heinkel was critical to Ohain's success with the turbojet in Germany and the lack of similar support explains why Whittle took twice as long in the UK. Finally, Siddiqi

(2000, p. 7) has described the rocket pioneers' alliance with Marshal Mikhail Tukhachevskii.

Tukhachevskii, Red Army chief of armament from 1931 to 1936, was the most important patron of jet propulsion in the Soviet Union between the wars.[9] At the outset he took the Leningrad Gas Dynamics Laboratory (GDL), founded in 1929, under the aegis of the Red Army's administration for military inventions to develop solid-fuelled rocket ammunition. In Moscow in 1931 a voluntary society of rocket scientists, the Jet Propulsion Study Group (GIRD), began to promote the cause of space exploration based on liquid-fuelled rocketry.[10] The group was led by Sergei Korolev, the future chief designer of ballistic missiles and space launch vehicles, and was sponsored by the civil defence organization Osoaviakhim. In September 1933 Tukhachevskii sponsored a merger of GDL and GIRD in a new establishment subordinated directly to him, the Jet Propulsion Research Institute (RNII).[11] He seems to have hoped to monopolize the development of jet propulsion as both funder and fundholder. He was frustrated by a decree of the Council for Labor and Defence which almost immediately transferred the new establishment to Sergo Ordzhonkidze's ministry of heavy industry.[12] This followed the precedent of arrangements for TsAGI and TsIAM, recently established to focus research in aircraft and aeroengine design respectively.

Although no longer the fundholder, Tukhachevskii personally, and the Red Army as funder, retained close involvement with RNII, contracting for much of its R&D output. RNII was an unhappy marriage, and divisions soon emerged between the weapons specialists of GDL and the space enthusiasts of GIRD. The new director I.T. Kleimenov, formerly head of GDL, curtailed work on liquid-fuelled rockets on the grounds of its low expected military utility, sidelining Korolev and the other GIRDers. The result was a huge row that embroiled RNII with the local party organization and pitched Korolev and Tukhachevskii against Kleimenov and Ordzhonikidze.[13] In 1935 Tukhachevskii exploited these divisions to recruit some former GIRDers led by Korneev, a dissident engineer whom Kleimenov had sacked, to set up KB-7 as a Red Army design bureau for liquid-fuelled rocketry (Siddiqi, 2000, p. 8). Thus Tukhachevskii succeeded in becoming a fundholder in jet propulsion by other means, although without a monopoly.

For several reasons unrelated to this theme Tukhachevskii was arrested in May 1937 and was executed as a traitor with many other officers (Stoecker, 1998; Samuelson, 2000). If there is a connection, it is that Stalin distrusted Tukhachevskii in part for his monopolizing ambitions which were strongly suggestive of a rent-seeking military-industrial lobby (Harrison, 2003b). After this, the cause of aviation jet propulsion lacked a high-level sponsor until Malenkov began to take an interest in 1943 and was briefed on the issues by aircraft industry minister Shakhurin.[14]

2. Citizen Initiatives

Many ordinary citizens with and without technical qualifications wrote to the Red Army with unsolicited ideas and suggestions for work on high-speed, high-altitude aviation, a few of which were taken up.

The files of the Red Army administration for military inventions show, for example, that in April 1932 and again in March 1936 one E.A. Blau submitted proposals for different aeroengines based on jet propulsion. These proposals were reviewed and rejected. One referee judged that "despite the fact that the author is an engineer [his designs] are distinguished by their naivety and demonstrate a complete absence of elementary information concerning jet propulsion."[15] Another file collects 51 proposals for jet, rocket, or turbine engines and airframes that were submitted in 1937, some professionally executed, some handwritten and childishly illustrated. One author proposed to lighten his superheavy airframe by filling the wings with hydrogen, neglecting the fact that a cubic metre of hydrogen generates only one kilogramme of buoyancy; another proposed a winged cruise missile but omitted to allow for a guidance system or automatic stabilization. Depending on its merits the response to each proposal was either a request for further information or a curt rejection.[16]

A special case is presented by GIRD, a voluntary society until it was merged with GDL to form RNII in 1933. The GIRDers were civilian engineers drawn together by a common interest; an official report describes them as "enthusiasts for the cause of rocketry who had no material base and no staff."[17] At first they won backing from Osoaviakhim, a state-sponsored voluntary association for civil defence. Their great achievement was the successful launch of the Soviet Union's first liquid-fuelled rocket in August 1933.[18] Then Tukhachevskii tried to take them over for the Red Army. This was the planned-economy equivalent of a friendly corporate takeover of a private high-technology start-up.

3. Foreign Specialists

In the late 1920s and early 1930s sympathetic foreigners with a technical interest wrote to the Red Army drawing its attention to the military significance of work on rocketry going on abroad and offering to promote such work in the Soviet Union. In 1932, for example, Rolf Engel, a German specialist in rocketry and communist party member or sympathizer, was referred to Tukhachevskii. According to biographical notes he had worked in German astronomy and as a member of the Verein für Raumschiffart (Association for Space Travel) at its test firing range outside Berlin. Engel volunteered a report on developments in rocketry in Germany and abroad, emphasising the breadth and depth of German developments. He also proposed to bring a group of specialists to the Soviet Union to collaborate with Soviet rocketeers.[19]

4. The Foreign Press

Established designers monitored the foreign press and worked up the information they found in order to demonstrate foreign progress, promote the cause of aerospace experimentation, and support bids for funding. If foreign press information was lacking, however, they still argued for increased funding on the grounds that foreign powers were evidently forging ahead of the Soviet Union in secret.

The Red Army chief of armament's files for 1931 testify to the pressure from below to take note of progress abroad and emulate it at home. This pressure was clearly related to funding decisions. For example, in May 1931 GDL director Petropavlovskii reported to the Red Army on work on rocketry abroad, mainly in Germany and the United States.[20] A number of German research groups and firms, including Junkers and Opel, were described as competing for patents and funding under the umbrella of a voluntary society for space travel including armed services representatives. The American scene was said to be characterized by a similar mix of commercial and military motivations. Petropavlovskii noted that rocketry could be applied to aviation as well as artillery, with the possibility of an aircraft with a primary rocket power plant capable of speeds of 1000 or more kilometres per hour. In a similar survey submitted at the same time the GDL rocket engineer Glushko emphasised that there was intense activity in western countries and that the basic difficulties in building rocket aircraft were close to solution; he concluded that "in the West both industrial and, particularly, military circles are keenly interested in the question of creating rocket shells and apparatuses."[21]

In the mid-1930s the absence of foreign press information was used to promote bids to fund foreign commercial trips. This was the reason that RNII director Kleimenov, for example, used three times in 1936 when asking permission to send his engineers abroad generally, on a tour of Germany, France, Britain, and America, and to the Paris air show.[22]

The foreign information available, although limited, was analysed exhaustively to support funding claims. In 1939 an article on developments in rocketry that had appeared three years earlier in the Italian journal *Revista Maritima* finally reached NII-3 director Slonimer.[23] The latter cited the article to demonstrate intensive German work on rocket munitions and asked for more money, supplies, and engineering personnel. He requested that the "appropriate organizations," presumably diplomats and spies, should seek out more information abroad, and applied to send a delegation from the institute to an armaments exhibition in New York.[24] The next year he made a similar request to send two specialists to Germany to find out more about work on rocketry there, and again he cited the *Revista Maritima* article in support.[25]

A survey of the historical applications of rocketry written in the ministry of the ammunition industry in 1939 noted that a veil of secrecy had descended over most military aspects of rocketry abroad; the little that was being published pointed to intense international rivalry in rocket technology. The examples cited were from a French work translated into Russian in the defence ministry.[26] A translation of an American article, also from 1939, listed the potential uses of rockets as ranging from field artillery to intercontinental bombardment and space exploration, and emphasised their ease of construction and use.[27]

The outbreak of war did not cut off press information. Following the maiden flight of the Whittle jet-powered Gloster E.28/39 in April 1941, *Flight* magazine published a series of articles about jet propulsion in London. These articles were collected in a booklet and republished by the magazine editor (Smith, no date). It seems to be in this version that they reached the Soviet Union. Their impact was significant. The booklet was circulated among designers; according to Gordon and Dexter (1999, p. 150) the description of the Italian hybrid jet of 1940, the Caproni-Campini N.1, encouraged staff at TsAGI in a similar design (see Table 1). In July 1944 minister of the aircraft industry Shakhurin copied many original *Flight* drawings to illustrate both existing and futuristic jet and turbine projects in a long briefing report for Malenkov.[28]

5. Foreign Commercial Information

Trade links gave some information to designers, but its value in lobbying for funding of jet propulsion projects was limited. In 1935 the aircraft designer Tupolev visited the United States for a second time, his first visit having taken place in 1929/30. He toured a number of aircraft factories. He saw nothing of American progress in military rocketry and his report was silent on the whole issue of jet propulsion.[29] This does not reflect secrecy; there was nothing to report because the Americans had nothing to show or hide. Surveys of the German aircraft industry were also carried out in the framework of the August 1939 nonaggression pact and these were reported to the ministry of the aircraft industry in September 1940. Here secrecy did play a limiting role; the Soviet delegations did not catch the least glimpse of the immense German activity in relation to new jet and rocket aircraft and artillery.[30]

There is no indication in the files that Soviet spies gained any information about progress in jet engines or rocketry in other countries. If they did, it did not reach the aeroengine designers.

E. Refinancing

When projects are long term, projects in progress require periodic refinancing. Alternatively, they must be discontinued. In this section we look at refinancing decisions affecting projects in progress to learn more about the incentives facing designers and funding principals and the calculations they made. When refinancing decisions were disputed, there was also a mechanism for conflict resolution: designers could and did appeal adverse decisions to higher authority, ultimately right up to Stalin.

1. Project Evaluation and Soft Budget Constraints

There were good reasons for governments to ration the funding of military aviation R&D. Most important was the fact that funding opportunities attracted both bad and good projects which those allocating research funding could not tell apart beforehand. This made it efficient for principals to ration the available funding across projects and through time. The various research establishments reported regularly to higher authority on each project in progress.[31] Through time funders could compare the progress of alternative projects in the hope of identifying the bad projects that should not be refinanced. In this way a form of rivalry similar to yardstick competition (Shleifer, 1985) could be exploited to increase principals' information.

By monitoring the progress of long-lived projects frequently, the funder could always obtain more information about the quality of projects than was available initially. Looking forward, by providing funding in installments and tying refinancing decisions to intermediate progress reports, the funder aimed to use the additional information to restrict financing to good projects. However, the funder could not always act on the information obtained. This was because of a weakness in the funder's commitment to act on this information after the event. Faced with poor intermediate results it could still be efficient to go on paying for a project that, in hinsight, the funder would prefer not to have initiated in the first place (Dewatripont, Maskin, 1995). This was because of sunk costs: since part of the project had already been paid for, the likely return was now increased relative to the fraction of costs not yet sunk. One result was that despite the funder's intentions budget constraints became soft *ex post*. Another was adverse selection: it gave R&D agents an incentive to understate needs and overstate expected returns so as to obtain the first instalment of funding. Once the first instalment was paid and had become a sunk cost, the payment of the next instalment became more likely. This meant that projects could continue to be refinanced even when they were known to be bad.

Soviet funding arrangements thus offered a degree of protection for self-serving interests. There was clearly rent seeking; was it intentionally tolerated at any level? Were bad projects deliberately fostered, for example, to share rents and promote loyalty? Some allegations of this nature concern the rocket designer and NII-3 director Kostikov. The background is important: Kostikov remains a controversial figure. His accusers resent the fact that he took the public credit for developing the famous *Katiusha* rocket mortar from its true inventor Langemak who was executed (Medvedev, 1978, pp. 36-7). They argue that Kostikov was not an accidental beneficiary of the purge at RNII but a willing instrument of Ezhov and Stalin, a renegade GIRDer who turned against his former comrades. They hold him at least partly responsible for the repression of Korolev and others (Siddiqi, 2003). According to Golovanov (1994, p. 512) Korolev carried a lifelong grudge against him for this reason. But Raushenbakh (1998, p. 66) considers the charge of complicity in the purge to be unfounded.

Serov (1997, p. 4) has suggested that Kostikov was unduly favored by Stalin in the wartime allocation of project funding. In November 1942 Stalin authorized the development of Kostikov's unproven design for the 302 rocket fighter, at a time when the development of new weapons in other fields was being ruthlessly suppressed in favor of mass production of existing ones. Serov notes the "practically unlimited financial possibilities" at Kostikov's disposal: 25 million rubles for NII-3-GIRT in 1943, compared with a similar sum for the Iakovlev and Mikoian aircraft OKBs put together. It is true that subsequently Kostikov was punished for the 302's failure: in the spring of 1944 he was sacked, then arrested. On the other hand his punishment was mild: he was released after a year in prison, and retained his military rank and medals. Golovanov (1994, p. 511) claims that "Stalin needed Kostikov, since [the latter] was one of the bearers of the Stalinist world order." Whatever that means, however, what we know of Stalin suggests that by this time he did not regard anyone as indispensible.

1. Adverse Decisions

In the quasi-market for inventions, projects developed out of initiatives at lower levels. The role of funding principals and planning decisions was reactive and tended to validate these initiatives. Consequently the refinancing of projects in progress was normal and we do not usually see explicit decisions to that effect except in those rare cases when verbatim minutes of discussion meetings were preserved (Harrison, 2003a).

A decision not to refinance a project in progress is illustrated from a file of the Red Army department of inventions.[32] In October 1937 engineer R.G. Sergeev of the design department of aircraft factory no. 22 at Fili submitted a proposal to design a 500- to 1000-kilogramme thrust rocket motor for an auxiliary flight booster, aircraft launcher, or rocket fighter. He based his proposal on a suggestion by the German specialist Eugen Sänger that had been published in an unnamed Swiss journal in 1936. He signed an agreement with the department of inventions on August 15, 1938 for the sum of 5000 rubles. He failed to complete the work promised, so his expenses were paid off in the sum of 1000 rubles only on September 26, 1940. We learn from this that small sums were easily written off.

Bigger decisions were more complicated. This is illustrated by the turbulent history of RNII. Frustration with the results of military R&D boiled over in the purges of 1937-8 (Harrison, 2000, pp. 128-30; Siddiqi, 2000, pp. 10-11; for previous accounts see Medvedev, 1978, pp. 34-7, 42-3; Holloway, 1982b, pp. 387-8). In May 1937 Tukhachevskii was arrested. The purge of RNII began in October with the arrest of director Kleimenov, Glushko, and others including the rocket mortar designer G.E. Langemak. In June 1938 work on the Korolev-Glushko rocket glider was suspended, the reasons given being the need to concentrate resources for rearmament on projects of more immediate military utility. A few days later Korelev was arrested, accused of being a

Trotskyist saboteur, and sentenced to ten years' forced labor. Impatience with the lack of results of Korolev's work on rocket aviation was clearly a factor. The testing of liquid-fuelled rocket aircraft was suspended while the rocket artillery programme was stepped up.

Why did these conflicts flare with such intensity? The conflict between artillerymen and space enthusiasts at RNII had simmered through the mid-1930s before the purge of 1937-8 swept the GIRDers away, taking several of their opponents with them. Siddiqi (2003) suggests that the technological uncertainties were simply too large to be settled scientifically on the basis of the limited funding provided by principals. This heightened the risks of R&D activity, and high stakes plus limited resources fed back into bitter infighting.

The end of KB-7 was decided by a combination of factors. The arrest of its sponsor Tukhachevskii created an immediate threat. At first KB-7 director Korneev staved off repression by joining in the destruction of the leading figures of RNII; he sent slanderous allegations to Stalin about Kleimenov.[33] In January 1938, with Tukhachevskii gone, KB-7 was taken away from the Red Army and handed over to the ministry of the defence industry where, like RNII (now NII-3), it was attached to the thirteenth chief administration for ammunition. But Tukhachevskii had devised KB-7 for the far-off development of liquid-fuelled rocketry, not the quick results now sought for immediate armament. For three years KB-7 had produced nothing to show for its outlays. The annual report of work of the thirteenth chief administration listed the projects completed under each institute or bureau and the weapons officially adopted by the Red Army for armament as a result. Under KB-7 the report for 1938 says only: "for armament in 1938 nothing supplied, in view of the long-term [perspektivnyi] character of work."[34]

In the atmosphere of the time KB-7 became an easy target. In early 1939 the Red Army resolved to close down a wide range of projects in ammunition R&D, not just those concerned with aviation jet propulsion, but including the work it was funding in KB-7. According to reports made to ammunition minister Sergeev, and forwarded by him to deputy defence minister Kulik, navy minister Frinovskii, and prime minister Molotov, the aggregate plan for ammunition research and experimentation for 1939 had been agreed among these ministries with the general staff the previous year.[35] In the course of disaggregating the plan and agreeing individual contracts with R&D establishments, however, the Red Army had unilaterally reneged on commitments worth 40 million rubles (out of 52.5 millions) and the Navy on 7.5 millions (out of 25 millions). Even after immediate cutbacks, 25 million rubles worth of research and experimentation remained without a sponsor, including two institutes that were entirely without funding. One was KB-7. Among the projects without funding at NII-3 were the Korolev-Glushko rocket glider and a ramjet project.

The effectiveness of these cancellations is not clear-cut. We do not know that either Voroshilov or Molotov gave Sergeev's protests a hearing. By the end of the year KB-7 had been closed down; according to Siddiqi (2003) the staff, starved of funding, turned on each other and eventually on Korneev too who was arrested and imprisoned. On the other hand the rocket glider and ramjet projects at NII-3 were evidently reinstated, and the Korolev-Glushko RP-318 made its maiden test flight in 1940 although the designers were absent and others got the credit. To judge from the annual returns shown in Table 3, NII-3 continued to expand during 1939 at a high rate, perhaps by absorbing the staff of

KB-7. But the funding of NII-3 was squeezed in real terms in 1940 and its expansion was brought to a sudden halt.

In short, in 1939 the funder lost patience with the designers' lack of results and tried suddenly to enforce a harsh constraint on the budget for research and experimentation. In the short term this attempt was only partly successful because the constraint was softened again by the fundholder's lobbying to reverse cutbacks, or by drawing on the fundholder's budget, or by some combination of the two. The efforts to squeeze R&D outlays may have continued in 1940.

Aircraft design yields a few cases of design organizations that were closed because of a lack of results (Albrecht, 1989, pp. 214-215). More frequently, the chief designers were imprisoned along with their teams, for example Bartini, Grigorovich, Miasyshchev, Petliakov, Polikarpov, Sukhoi, and Tupolev. Kalinin was executed (Albrecht, 1989, pp. 133-6). These and episodes such as the purge of RNII gave credibility to subsequent threats of extreme penalties for failure. Those charged with designing the Soviet Union's first atomic bomb, for example, all expected to be arrested if it failed to detonate (Holloway, 1994, p. 215; Simonov, 2000, p. 154). The credible penalization of individuals for R&D failures helped to compensate for the weakness of the the principal's commitment to penalize organizations financially for lack of results.

2. Appeals Against Adverse Decisions

Some designers appealed to higher authority against threats to project financing. In a related context Markevich and Harrison (2004) note that "written appeals to higher authority were a general feature of life in a society with underdeveloped legal enforcement, and citizens in all walks of life used them to seek truth and justice." Disputes within RNII were a plentiful source of petitions. In May 1934, for example, both Korneev and Korolev complained to party and military authorities over RNII director Kleimenov's suppression of liquid-fuelled rocket projects.[36] After the RNII purge, Korolev appealed from prison to the prosecutor (Raushenbakh, 1998, pp. 61-4), but he also wrote to both Beriia and Stalin personally (Golovanov, 1994, pp. 286-9) to protest his innocence and ask to be allowed to return to work.

For a petition to carry weight at higher levels the appellant had to invest something in the outcome; thus it was normal to support an appeal by listing the writer's progress in the cause at hand. In effect the appellant offered her specialist reputation as a hostage (Williamson, 1996, pp. 120-144) to support the transaction sought. But most inventors do not usually have much reputation in their lifetimes. Most people are lucky to have even one great idea, let alone carry it out; as a result, the past is a poor guide to an inventor's future performance and this is true both before *and* after she has actually invented something. At a given point in time most inventors either have nothing to show for their efforts or they are failing to live up to the promise of past achievements. Thus an inventor's reputation is hard to establish and harder to maintain.

Some other kinds of reputation that could be brought into the equation were also fragile, for example, a reputation for loyalty to superiors. In the 1930s all were familiar with the figure of the careerist who accumulated this reputation strategically, so as to spend it later. Winning a reputation for loyalty to vertical superiors was also a good way of making enemies out of horizontal rivals. Those with more energy than talent, who risked their credit with higher levels without the talent to back it up, invited destruction as the fate of Korneev in 1939 suggests.

According to Serov (1997, p. 4), Liul´ka was known as a "complainer" [zhalobshchik]. Having already failed in an appeal to minister Shakhurin of the aircraft industry, he wrote to Stalin of May 1942 asking to be allowed to go back to work on the turbojet. This appeal is a rarity: unlike most, it had the desired result.[37] Serov (1997, p. 3) suggests that in Liul´ka's case it may have suited rivals to go along with his petition in order to raise the profile of the issue in their own interest. Korolev's similar appeals from prison met with the more usual response: they were ignored. It is true that Korolev was subsequently transferred from the Kolyma labor camps to the NKVD *sharaga* at factory no. 16 in Kazan´ but this, according to Raushenbakh (1998, p. 66), was entirely the result of Tupolev's desire to recruit him.

F. The Secondary Asset Market

When projects are long term their need for refinancing has the necessary effect of creating a secondary asset market. This section gives a brief account of the market for R&D projects and the kinds of behavior that can be observed.

According to the principle of the command economy the ownership of each project by a ministerial fundholder could only be transferred by a centralized decree. In reality there were substantial incentives for officials to mount takeover or merger bids for projects of other fundholding authorities. The attraction of a project in progress lay in the sunk costs that had already been incurred at the expense of others to whom the new fundholder did not have to pay compensation. Even if the transfer was of people rather than physical assets, the project personnel brought with them accumulated tacit knowledge which formed significant intangible capital. The costs of takeover were political rather than financial. First, a bid required the payment of direct lobbying costs. Second, it required the expenditure of reputation; a successful bidder made promises for which he might later be held to account. Third, it weakened the centralized enforcement of ownership rights over assets on which all fundholders ultimately relied. However, circumstances could easily arise in which it was more dangerous to abstain from the secondary market than to enter it.

These can be readily translated into the costs and benefits to a proprietary dictator. In Olson's (1993) metaphor Stalin resembles a bandit chief who settles on a territory and monopolizes it so as to maximize the rents from it. But in secondary markets that formed under his regime, lesser bandits roved. Up to a point this could benefit the economy; it reallocated resources to those who would put them to better use. But the standard of valuation of "better use" was private not social. Since the losing side did not recover the social value of their assets the fear of expropriation weakened the dynamic incentive to invest rather than seek rents. Finally, even if static allocation improved, the dictator's control over the production and sharing of rents was likely to be weakened.

In the secondary market for R&D assets the transactions that we observe were of two kinds. First, there were horizontal mergers and takeovers, sometimes hostile. Second, from time to time the NKVD swooped down from above to confiscate projects using its powers of arrest and confinement.

Any organization could take part in the secondary market, and small organizations could be as aggressive as large ones. There were few advantages to being small in the command system other than the chance of being overlooked. As an example of the latter, to work in a small outfit like KB-7 in 1937 meant two more years of life expectancy compared with working in the larger and more prominent RNII. Usually, however, it was better to be large. Large units could realize significant economies of scope; they were less reliant on outsiders for essential goods and services. There were also managerial economies of scale. Ministerial officials tended to promote larger units on the grounds of alleged economies of scale in research and this was reflected in the frequent calls to concentrate effort and eliminate duplication or "parallelism." Whether these economies really existed is another matter. Rationalization and concentration were were regarded as progressive almost beyond debate and their advantages were seldom questioned, especially when comparisons were made with the scale of R&D establishments in aeroengineering abroad.[38] But as long as ministers believed in them, bigger organization had the advantage. As a result, larger units were continually on the lookout for favorable rationalizations opportunities, while smaller units also had to grow, if necessary at the expense of others, or risk being swept up by rivals at any time.

The logic of the takeover bid was a call to write off the past. Consider a failing project, one that had incurred significant sunk costs without giving results on schedule. Was the project intrinsically bad, underfunded, or poorly led? If the lack of results could be reasonably attributed to lack of resources or organization, then it was efficient not only to write off the sunk costs but also to refinance the project under new management. This logic may have been stronger when the scope of activity and the number of projects were increasing because growth was likely to mean an increasing number of potentially weak projects. Thus proposals for takeovers and mergers were particular evident in the years 1937 and 1938 during and after the purge of RNII.

The purge sparked a bid to rationalize research on jet engines. Staff of the Academy of Sciences Institute of Theoretical Geophysics wrote to prime minister Molotov at the end of December 1937; Molotov's secretary forwarded it to both defence minister Klim Voroshilov and deputy minister for the defence industry Kaganovich for comment.[39] The authors highlighted the unmet needs of Soviet aviation in contrast to the resources being devoted to jet aeroengine development by the "capitalist countries," the designs being pursued by Breguet and Junkers in France and Germany, and the veil of military secrecy which was hiding real progress abroad. They ascribed resistance to jet designs in the Soviet Union to a coalition of "enemies of the people" including designers such as Langemak of RNII and soldiers such as Efimov, chief of the Red Army artillery administration. As for the established jet engineers such as Merkulov, they charged them with "creating 'conditions' of work bordering on mockery" (the phrase "bordering on" could have been significant: not *actually* mockery, just bordering on it). They called for pure and applied research encompassing ramjets, pulse-jets, and hybrid engines to be scaled up and personnel and projects concentrated in KB-7, which the Red Army should hand over to the defence industry.

Although the Institute of Theoretical Geophysics had no clear interest in the fortunes of KB-7 its intervention was probably not altruistic. The chances are that someone had put them up to it. The bid failed, however. Kaganovich called on the new NII-3 director Kostikov for comment. The latter presented a strongly argued case for his own institute to be the new centre for jet engine R&D, based on a short scientific review of jet concepts and experimental results. He concluded that it was essential to draw into this line of work people "closely involved with aviation technology" as opposed to those "incidentally showing an interest" (this was a slighting reference to KB-7); Kaganovich in turn supported the NII-3 position.[40] So did the Army: the new air force chief Loktionov wrote to Voroshilov supporting the writers of the Institute of Theoretical Geophysics on the principle of giving more priority to jet engines but rejecting the case for KB-7 on grounds that the latter lacked the necessary research and production equipment. He recommended NII-3 as the new centre for jet engine development, and deputy defence minister Fed´ko relayed these arguments to Molotov adding a proposal that NII-3 absorb relevant personnel of KB-7.[41] This was the eventual outcome, although KB-7 survived until the end of 1939.

As has been seen, the years 1938 and 1939 saw high mortality among aviation jet propulsion projects; in 1939/40 there were several new start-ups. Therefore it is no surprise that, in his memorandum of February 1941 to deputy prime minister Voznesenskii, minister of the aircraft industry Shakhurin listed the various ongoing projects and proposed "to concentrate all the work in progress in [NII-3] of the ministry for the ammunition industry […] and transfer the institute to the ministry of the aircraft industry," enclosing a draft decree to that effect.[42] This particular bid failed for the moment, or was overtaken by events; after the outbreak of war NII-3 was first subordinated directly to the central government, and handed over to the aircraft industry only in 1944.

Finally, when the R&D agents were seen to have gone too far their own way, Stalin used his security agency to force them back into conformity with the priorities of state. As is well known the NKVD arrested a number of aircraft and aeroengine designers in the purges of 1936-8 and used them to formulate proposals for implementing new designs. A number of aircraft designers from TsAGI, TsIAM, and the Tupolev design bureau, including Tupolev himself, were held at factory no. 156 (Ozerov, 1973), then reorganized as TsKB-29. Of the RNII personnel arrested in 1937, some were shot and the rest sent to labor camps; some survivors were subsequently recalled from the Kolyma and put to work in the aeroengine *sharaga* at factory no. 16 in Kazan´ (Golovanov, 1994, pp. 318-28).

To summarize, was the secondary asset market "real" or just a quasi-market? The dictator did not intentionally create or authorize it; the buyers and sellers were independently self-interested; and the dictator seem to have made little attempt to align their interests with his own. But there was no equilibrating process, and enforcement rested exclusively with the dictator. For these reasons it would be a mistake to think of it as a real market, but still the lines are blurred; although only a quasi-market, the secondary asset market had some strongly "realistic" features.

G. Closing the Quasi-Market for Inventions

This section describes the end of the Soviet quasi-market for inventions in jet propulsion. The market was closed down between 1944 and 1946. By 1944 Germany had revealed the breakthroughs that had been in preparation for so many years, launching jet fighters and bombers and a rocket fighter into aerial combat and firing jet powered cruise missiles and ballistic rockets at London. The fog of technological uncertainty was gradually blown away, and this gave the authorities the information they needed to recapture centralized control over aerospace innovation.

The new phase began on February 18, 1944 when Stalin's war cabinet, the GKO, resolved to give new attention to jet propulsion technology. There was a certain amount of the usual reorganization and redesignation, so GIRT, under direct control of the central government since January 1942, was renamed the Research Institute for Jet-Propelled Aviation (NIIRA) and then Research Institute no. 1 (NII-1) of the aviation industry. A further decree dated May 22, 1944 commissioned a number of aircraft designers to fit rocket and jet boosters to existing propeller-driven aircraft; Lavochkin was to build a turbojet aircraft; Glushko, Dushkin, and Isaev were to work on new rocket motors, and Liul´ka and Uvarov were to work on jet engines; by 1945 Liul´ka was roughly where Whittle had been in 1939, with an engine, the S-18, ready for ground testing but not for flight (Egorov, 1995, pp. 413-24, 431-6).

From this point there began a marked change in the organization of aviation R&D. Regimentation and drilling increasingly took the place of initiative and networking. This process was aided by a political shock to the designers, fundholders, and funders: the "aviators' affair" of early 1946 in which leaders of the air force and aircraft industry were arrested and imprisoned. At the end of the war Stalin concluded that the Soviet Union was lagging in aircraft and aeroengines because relationships between the air force and the leading aircraft design bureaux had become too cosy, enabling favoured designers to establish monopolies and relax the pace of development (Bystrova, 2000, pp. 320-1). The purge also had wider political dimensions that do not concern us (Pikhoia, 1998, pp. 45-7).

A meeting in the ministry of the aircraft industry in March 1946 whipped the design sector of the industry into line. The new minister Khrunichev promoted the solution as "raising the initiative of the chief designers" and "lifting the design bureaux and research institutes towards more intiative-led work [initsiativnaia rabota]."[43] What this meant in practice was a demand for fewer failures, less seeking of rents, and more accountability:[44]

> […] we should not take the path of adventurism, we don't have to spend money on any project [just] in order to convince ourselves that the expenditure was pointless […] Until now we convinced ourselves of the lack of profit in one or another project or new design [only] after the development work […] In future we must change the system and test a person's ability over a fixed period of time. Here I have to say that a thousand objections will be raised, they'll say "They're hindering us, they're not giving us the chance to work." In the context of a rational state approach we must sweep aside all such discussions so that this business isn't taken over by demagogy. We have to find the grain that will give the state the necessary yield.

The aircraft designer Il´iushin, first in discussion, developed the point: [45]

> Our resources are limited. We must review all the aircraft and engine types, throw all our resources into them, and move the matter forward. We shouldn't throw a single extra kopeck where it isn't needed. For this, our aviation industry has to stop looking at design bureaux as "free" organizations in the spirit of: "if something works out that's good, and if it doesn't no one has to account for it." The ministry of the aviation industry is accountable for the work of the design bureau. That's clear to all.

The outcome was that during 1945 the German jet engines and aircraft were inventorized and allocated for further investigation and development to research institutes and design bureaux grouped under a new chief administration for jet-propelled aviation within the ministry of the aircraft industry.[46] As the scope of research and design work widened, a relentless process of regular target-setting and monitoring set in. Government decrees set targets. The industry's progress towards each target set by the decree of April 22, 1944 was rigorously monitored.[47] By 1947 the industry plan for experimental work on aeroengines for 1947 listed 48 separate projects of which 38 were for jet or rocket engines; against every project was noted the government decree that authorized it, the technical parameters set for it, and the deadlines for completion and handover for external assessment.[48] There was still rivalry, but it is hard to imagine anything more different from the designer-led, uncoordinated rivalry of the 1930s.

It took nearly two years to close the quasi-market fully; the length of time required may seem surprising. The reasons are to be found abroad: just at the time the authorities were trying to close down the market at home, two completely new markets for inventions sprang up outside the country. To add to the confusion, each market was specialized in a different, competing version of the turbojet.

One market was in the Soviet zone of occupied Germany and this market continued to grow actively for more than a year after the end of the war. On offer in this market were BMW and Junkers turbojets with axial-flow compressors on the same scheme as Liul´ka. The German designs were low powered and unreliable, however. The German market was not closed until October 1946 when Stalin authorized the wholesale deportation of nearly 3,000 rocket and aviation specialists from eastern Germany. Once on Soviet territory they came under the direct control of the MVD which accommodated them for several years and managed their work in a number of specialized *sharashki* (Sobolev, 1996, pp. 58-118; Harrison, 2000).

The other market was a real international one. The original Heinkel and Whittle jets had used a radial compressor, which gave superior reliability although with a large front profile and limited scope for scaling upwards. Further down the same road, Rolls Royce was now manufacturing reliable engines that were efficient for their size. In 1946 the British government agreed the sale of 25 Rolls Royce Nene engines to the Soviet Union, followed by 30 Derwent V engines (Shavrov, 1988; Egorov, 1994).

At the end of the process the Soviet Union had a jet aircraft industry with engines that came from three genetic branches: German, Soviet, and British. In 1946 the BMW and Junkers axial-flow engines were copied and installed in the Soviet Union's first jet aircraft, the experimental Iak-15 and twin-engined MiG-9, but were not developed further. In 1947 a Soviet jet engine, Liul´ka's axial-flow TR-1, was at last developed for the twin-engined Su-11 fighter. Also in 1947 the Rolls Royce radial-flow Derwents were rapidly assimilated and developed for the Iak-19 fighter while in 1948 the Nenes were installed in the Soviet Union's first serial production jet fighter, the MiG-15.

H. Payoffs, Reputation, and Enforcement

To summarize: For a decade and a half the field of jet propulsion was marked by technological uncertainty and information bias: specialists knew more than the officials who funded them. Under these conditions centralization was out of the question. Instead, a quasi-market for inventions evolved with a secondary quasi-market for research assets alongside it. Both markets had significant "realistic" features, and rivalry in both was regulated with difficulty. When the uncertainty was resolved, however, the market was closed down.

In this section I address the issue that remains: how, in the period of uncertainty, could this rivalry have produced any successes at all? The rewards that funding principals offered to inventors were small, distributed as much for time serving and loyalty as for achievement, and could be taken away at any time. In such a setting we would expect agents to continue to invest their efforts in seeking to share the available rents rather than in making profits from inventing something new and useful.

As a first pass at this problem, it would seem that successful designers were strongly motivated by two things that were very valuable and could not be confiscated. One was intellectual curiosity and a desire to solve the intrinsically interesting problem at hand, strengthened in some cases no doubt by the desire to escape from a crazy world into a bubble of scientific rationality. The other was the reputational gain attached to priority in invention. A significant aspect of this reputation is that it was not in the gift of the Soviet state, although we shall find circumstances in which the state could steer its allocation; rather, it was awarded by the "Republic of Science." I borrow this phrase from Dasgupta and David (1994) but the context suggests a departure from their framework. Dasgupta and David contrast motivations and incentives in Science with those in Technology: in their terminology scientists do research so as to gain priority in discovery, and technologists engage in innovation, which is replicative of scientific discovery, so as to make profits. In the present case it is obvious that technologists could achieve priority not by discovery but by invention. Where invention is concerned, therefore, Technology is like Science.

I do not mean that the position and salary that the state provided were completely unimportant. Specialists at the global frontier of military technology had material aspirations for themselves and their families just like other people, and research and design work could help them towards such goals. The cash value of the potential rewards was substantial. To give a rough idea, the average monthly pay of specialist ("engineering and technical") workers at NII-3 in the first quarter of 1941 was 818 rubles, roughly two and a half times the average industrial wage of 1940.[49] More detail is available for the 250 "management and administrative" staff of Liul´ka's aircraft factory no. 165 in August 1946; this category included everyone from the chief designer (6000 rubles a month) to the floor sweepers in the labs (200 rubles). The median monthly wage was 875 rubles, compared with 626 rubles for the average industrial wage in December of that year (Filtzer, 2002, p. 235). It was enough to staff the factory fairly fully; there were only eight vacant posts, of which seven offered less than 400 rubles.[50]

Nominal pay was just the start. Work in military R&D also gave access to plentiful bonus payments and awards. Director Slonimer of NII-3, for example, is quoted as having received 19,250 rubles on top of his salary in 1939 and the first half of 1940.[51] The evidence is fragmentary and we have no clear picture of how such sums were fixed or allocated. On the face of it officials made recommendations to mark significant achievements, transitions, and anniversaries.[52] To put it another way, it seems possible that any excuse would have done. This is certainly the impression given by prewar investigations which threw up many alleged cases of unjustified side payments and awards. A finance ministry audit of defence industry research establishments in 1938 found that TsIAM, the lead organization for aeroengine development, was running no less than 19 separate incentive schemes on which it had spent 1.2 million rubles in 1937 along with another 200,000 rubles on rest cures and sickness benefits.[53] An audit of NII-3 two years later not only threw up Slonimer as a case of unjustified side payments but also alleged that Slonimer had used incentive schemes to pay off his colleagues and bosses.[54]

Whether we should fully trust such accusations is another matter; a lot of unfounded allegations were flying around at that time.

Also of significance equal to nominal pay in a shortage economy was the privileged consumer provisioning available to those whose jobs gave them the right to a Moscow residence permit. Mukhin (2004) has shown that in the 1930s Moscow-based aviation specialists could be persuaded to relocate to the provinces only with great difficulty, and then only when the ministry guaranteed their future right of return. This applied whether "the provinces" were hundreds of kilometres away or only just outside the city limits.

In short there is no doubt that working in aviation R&D offered good pay and a reasonable life style for the time. But that is not the point. The point is: was this the mechanism that motivated inventive effort rather than time serving?

This seems unlikely for three reasons. First, Frey (1997) has analysed labor markets where agents are strongly motivated by intrinsic incentives such as satisfaction or reputation. He concludes that, where intrinsic incentives are strong, they are weakened by external attempts to control motivation by substituting cash. In short, when morale matters, manipulation is demoralizing. Thus, supposing the Soviet state had been capable of targetting monetary incentives accurately on inventive effort, the result was likely to have been counterproductive. Second, as a matter of historical fact the state does not seem to have had this capability. Rather, the incomes and rights of residence of aviation designers went with position rather than success. Third, it is clear that the state could and did confiscate income, rights of residence, and position at any time.

There were always safer ways of earning a living than by designing military equipment. If that was what one had to do, then it was safer to be paid less, not more. In 1950, for example, Stalin suddenly accused his favorite aircraft designer Iakovlev (2000, p. 395) of diverting state funds into excessive salary and bonus payments: "Do you know what they say about you behind your back? They tell me you're a thief." What saved Iakovlev was the support of his boss, minister of the aircraft industry Khrunichev, who proved to Stalin that Iakovlev's design team and production workers were fewer in number, lower paid, and less well equipped than those of the other designers.

In short, while position and pay should not be neglected, they can hardly be regarded as credible payoffs for an inventor's lifetime effort. Something else that was very valuable had to be available to overcome the fear of expropriation. This is why I look for another mechanism to explain their motivation, and I find it in the one thing that could be credibly offered since it was in the gift of the Soviet Union's rudimentary civil society rather than of the Soviet state: reputation for priority.

To demonstrate the high value and decisive importance of reputation for priority in practice, I offer four kinds of evidence. First, when it turned out that a given problem had already been solved abroad we find that Soviet designers were reluctant to put effort into replicating foreign experience or to accept foreign advice. When Stalin ordered the deportation of thousands of German specialists in atomic science, aviation, to the Soviet Union in 1946 it appeared that his country was gaining priceless human capital, but in fact it was difficult and at times impossible to persuade Soviet designers to collaborate effectively even when the Germans were willing (Harrison, 2000). In the nuclear industry Soviet designers were reluctant to copy from American designs without introducing their own trademark innovations, not all of which were successful (Lebina, 2000). Notably, Beriia tricked the designers of the first Soviet atomic bomb into replicating the work done at Los Alamos by making them believe that they had the priority; he had their leader Kurchatov guide their work on the basis of intelligence reports in such a way that they thought they were breaking all the ground themselves and did not know that they were merely following in Oppenheimer's footsteps (Holloway, 1994). The low status of replication generally (Wible, 1998, pp. 23-42) then helps to explain why a country so rich in invention could be so poor at innovation (Berliner, 1976; Amann, 1986): the same mechanism could not promote both.

Second, we find that Soviet designers feared plagiarism before the event. Harrison (2003a) provides two cases: in one, a steam turbine designer defied a direct order from a ministerial superior to share progress with rivals and so accelerate progress; those involved were clear that the desire to protect his personal priority was the motive. In another case the gas turbine designer Uvarov put up a barrage of excuses to shut interested observers out of his work; he argued that it was too secret to share with naval designers who wanted to find out what he was up to. A cynic might wonder whether these specialists just wanted to hide their own lack of progress, but Uvarov at least was a serious pioneer who had real claims to protect.

Third, it is evident that nothing caused more lasting personal bitterness in the "Republic of Science" or gave rise to a deeper desire for personal vindication than the exceptional cases in which the temporal state intervened in the process of attributing priority and caused a reputation for priority to be suppressed or enabled it to be stolen. A claim that was suppressed was to the Soviet Union's first and the world's second rocket aircraft which the future chief missile designer Korolev developed in the late 1930s; he was arrested and imprisoned in 1937 while it was in development, leaving it to others to fly it for the first time in 1940. A claim that was stolen was to the Katiusha, the famous rocket mortar of World War II; Langemak developed it but the new NII-3 director Kostikov took the public credit for it after Langemak was arrested and shot in 1937 (Siddiqi, 2000, p. 25).

Fourth, the high value of reputation for priority is confirmed by the fact that, when it ceased to be available as an incentive for the aviation designers, the government had to replace it with some other inducement and this took for the form of side payments that were extravagantly large by comparison with anything previously offered. By 1944 it was clear that the Germans and British had solved the principal problems of jet reaction. Thus, Soviet designers could no longer win a worldwide reputation for priority. Korolev and Liul´ka could be the fathers of *Soviet* rocketry and the *Soviet* turbojet but no more than that. As far as Stalin was concerned the priority was now to copy the west; replication had to come before invention. Government decrees of April and June 1946 and May 1947 now set the designers in an organized competition with each other, setting design targets and offering enormous cash prizes to the design teams and chief designers that met them. First prize in the aircraft competition included *700 thousand* rubles for the chief designer together with an Order of Lenin, a Stalin Prize, and a luxury ZIS-110 private car, and many more hundreds of thousands of rubles, apartments, cars, and medals to be shared among his deputies and design staff.[55] Something similar was also on offer to the aeroengine designers; in the spring of 1948 Liul´ka was given a Stalin Prize (third class) and was personally awarded 600,000 rubles, or 100 times his monthly pay in 1946, with a further 800,000 rubles for his design team; he got another Stalin Prize the next year, upgraded to first class.[56]

In short, the designers themselves regarded a reputation for priority in their field as extremely valuable, were ready to take considerable risks to establish and protect it, and regarded attempts to infringe on it as one of the most heinous crimes, equivalent to a deadly physical assault. To obliterate a person's achievement was as bad as to destroy them physically. When money took the place of reputation, enormous sums were required.

Finally, markets for inventions had some common features in all countries. Fears of plagiarism and confiscation were ever present in Whittle's calculations. Because he was a serving officer the British government as funding principal held "Free Crown User" rights over his patents (Whittle, 1953, p. 47) and could and eventually did do with them as it wished. Whittle had hoped (1953, pp. 102-3) to profit from the development and manufacturing. He also feared theft by Rover, an interim collaborator (1953, pp. 115-16, 205-6), but in the end the government handed the business to Rolls Royce. For his ultimate reward Whittle had to make do with £100,000 from Parliament, a knighthood from George VI, and an FRS from the Republic of Science. As for Germany, according to Ohain (Ermenc, 1990, pp. 30, 40-1) Heinkel saw no protection in patents and defended himself by keeping the German air ministry in ignorance until the first test flight; Ohain also regarded patents as worthless. In the end the big German contracts for wartime mass production of jet engines went to BMW and Junkers, not Heinkel; this was less an act of confiscation than a punishment for pursuing a radial-flow concept when German aviation officials had decided, correctly, that the future lay with the axial compressor (Kappus in Ermenc, 1990, pp. 72-5).

Conclusions

To conclude: Jet propulsion R&D was carried out in the context of a vertically organized command system. In the interwar period the technological uncertainty was so great that it could be processed only in a market-like context. There was a quasi-market for inventions with horizontal rivalry, competitive rent-seeking, and attempts to bar entry and create monopolies. A secondary quasi-market in research assets also sprang up that involved takeover and merger activity.

Designers created the quasi-market for inventions and held the initiative in it. There were more initiatives than the authorities were willing to fund. Inventiveness was not in short supply. The authorities' main problem was to control it, not promote it.

In the Soviet Union jet propulsion R&D was an artisan industry. The resources available to fund research were extremely limited and funding was rationed. Budget constraints on individual projects in progress tended to become soft, however. Once a project had been selected for funding it had a good chance of its funding being continued until aggregate limits on the funding principals' resources and patience were breached.

It was difficult or impossible for the authorities to know whether they were getting value for money. Designers who succeeded in getting initial funding and subsequent refinancing were "heterogeneous engineers." They invested resources in lobbying and political reputation to ensure that their projects were selected for funding and, once selected, to protect them against termination from above or takeover by rivals in the name of rationalization.

When faced with adverse funding or career decisions or takeover threats designers retained the option of appealing to higher instances in the vertical hierarchy. The success of such appeals rested in part on technological reputation, but an inventor's reputation was difficult to establish and appeals were rarely successful.

A reputation for priority was one reward for successful invention and it was the only reward that the state could not easily steal or confiscate after the event. This is because reputation for priority was bestowed by the "Republic of Science" (or Technology), not by the state. Some evidence of the value of a reputation for priority is that, once it could no longer be won, the state had to replace it with individual incentives valued at hundreds of monthly paychecks.

The state's exploitation of the value of reputation for priority explains why the market for inventions worked, despite the fact that it was only a quasi-market, not a proper market. Selective decentralization was effective under these conditions partly because the incentive mechanism on which it relied was assured and enforced by an external party: the Republic of Science. By definition, however, the quasi-market for inventions was the only one that could be made to work this way; its particular reputation mechanism would be powerless in any activity that involved replication, that is, in most areas of economic life.

Appendix. Soviet R&D Projects for Jet Propulsion in Plans and Reports, 1932 to 1944

Year	Date	R&D Organization	Designer	Design Object
1932	July 4	GDL	Glushko	Rocket motor
1932	July 4	VTI	…	Gas turbine
1934	Jan. 23	RNII	…	Aviation boosters
1934	Jan. 23	RNII	…	Rocket motors
1934	May 10	MAI	…	GT-1 gas turbine
1936	Dec.	VTI	…	GT-1 gas turbine
1936	Jan. 8	VTI	…	GT-1 gas turbine
1936	April 28	RNII	…	Rocket glider
1936	Dec.	RNII	…	Ramjet
1936	Dec.	RNII	…	Liquid-fuelled aviation rocket motor
1936	Dec.	RNII	…	Rocket glider
1937	…	RNII	…	Rocket glider
1937	Feb. 28	VTI	Uvarov	Gas turbines GTU-3, GTU-5
1938	Feb.	VTI	…	Gas turbine
1938	Feb. 4	KB-7	…	Ramjet
1938	Feb. 4	NII-3	…	Ramjet
1938	Dec. 9	VTI	Uvarov	Gas turbine GTU-3
1939	…	KB-7	…	Liquid-fuelled rocket motor
1939	…	NII-3	…	Rocket glider RP-318
1939	April 9	NII-3	…	Ramjet
1939	June 4	KB-7	…	Liquid-fuelled rocket motor
1939	June 4	NII-3	…	Liquid-fuelled rocket motor Hybrid jet engine
1939	June 4	VTI	…	Gas turbine
1939	Oct. 20	NII-3		Rocket glider
1939	Dec. 10	…	Uvarov	Gas turbine
1939	Dec. 10	TsKTI	Liul´ka Merkulov	Air jets
1940	Jan. 13	NII-3	…	Rocket glider Ramjet Hybrid jet engine
1940	Sept. 17	NII-3		Rocket glider Ramjet Hybrid jet engine
1941	Jan. 14	NII-3	…	Ramjet Hybrid jet engine
1941	Mar. 20	TsIAM	Uvarov	Gas turbine GTU-3

Year	Date	R&D Organization	Designer	Design Object
1941	Feb. 5; Apr. 5	Z-1	Merkulov	…
1941	Feb. 5; Apr. 5	Z-28	Bas-Dubov Zaslavskii	…
1941	Feb. 5; Apr. 5	NII-3	…	Hybrid jet engine
1941	Feb. 5; Apr. 5	SKB-1	Liul´ka	Axial turbojet
1941	Apr. 12	NII-3	…	Ramjet Hybrid jet engine Liquid-fuelled rocket motor for interceptor aircraft
1941	July 30	NII-3	…	Ramjet Hybrid jet engine Liquid-fuelled rocket motor for interceptor aircraft
1941	Aug. 7	NII-3	…	Ramjet Hybrid jet engine Liquid-fuelled rocket motor for interceptor aircraft
1941	Dec. 30	NII-3	…	Ramjet Hybrid jet engine Liquid-fuelled rocket motor for interceptor aircraft Rocket booster
1942	Jan. 5	NII-3	…	
1942	May 4	NII-3	…	Ramjet Hybrid jet engine Liquid-fuelled rocket motor for interceptor aircraft Rocket booster
1942	May 7	NII-3	…	Ramjet Hybrid jet engine
1942	May 29	NII-3	…	Ramjet Hybrid jet engine Rocket interceptor aircraft
1942	June 8	OKB-293	Bolkhovitinov Dushkin Liul´ka	BI fighter with liquid-fuelled rocket motor
1942	Aug. 10	OKB-293	Liul´ka	Turbojet
1943	May 20	TsIAM	Liul´ka	Turbojet
1943	Oct. 22	Z-84	Merkulov	Ramjet
1943	Oct. 22	GIRT	…	Liquid-fuelled rocket motor for BI
1943	Oct. 22	KB Z-16	Glushko	Liquid-fuelled rocket motor

Year	Date	R&D Organization	Designer	Design Object
1943	Oct. 22	OKB-293	Bolkhovitinov	BI fighter with liquid-fuelled rocket motor
1943	Oct. 22	TsAGI	Abramovich	Hybrid jet engine
1943	Oct. 22	TsIAM	Liul´ka Uvarov	Turbojets
1944	…	KB Z-16	Glushko	Rocket motor
1944	…	NII-3	Dushkin Isaev	Rocket motors
1944	…	NIIRA	Liul´ka	Turbojet
1944	…	TsIAM	Fadeev Kholshchevnikov Tolstov	Hybrid jet engine
1944	…	TsIAM	Uvarov	Turboprop
1944	July 16	KB Z-16	Glushko	Rocket motor RD-1
1945	Mar. 20	Z-16	Glushko	Single chamber liquid-fuel rocket
1945	Mar. 20	NII-1	Dushkin	Two chamber liquid-fuel rocket
1945	Mar. 20	TsIAM	Kholshchevnikov and Fadeev	Hybrid jet engine
1945	Mar. 20	TsIAM	Tolstov	Hybrid jet engine
1945	Mar. 20	NII-1	Isaev	Single chamber liquid-fuel rocket
1945	Mar. 20	NII-1	Dushkin	Single chamber liquid-fuel rocket
1945	Mar. 20	TsIAM	Uvarov	Turboprop
1945	Mar. 20	NII-1	Liul´ka	Turbojet
1945	April 4	Z-16	Glushko	Single-chamber liquid-fuel rocket
1945	April 4	NII-1	Isaev	Single-chamber liquid-fuel rocket
1945	April 4	NII-1	Dushkin	Single-chamber liquid-fuel rocket
1945	April 4	TsIAM	Kholshchevnikov and Fadeev	Hybrid VK-107A
1945	April 4	NII-1	Liul´ka	Turbojet
1945	Nov. 10	…	Kholshchevnikov Fadeev	Hybrid jet engine
1945	Nov. 10	…	Glushko	Three rocket motors
1945	Nov. 10	…	Uvarov	E-3080 turboprop
1945	Nov. 10	…	Tolstov	Hybrid jet engine
1945	Nov. 10	…	Isaev	Liquid-fuelled rocket
1945	Nov. 10	…	Liul´ka	S-18 turbojet
1945	Dec.	…	Glushko	Three-chamber liquid-fuel rocket
1945	Dec.	NII-1	Isaev	Single-chamber liquid-fuel rocket
1945	Dec.	NII-1	Dushkin	Single-chamber liquid-fuel rocket Two-chamber liquid-fuel rocket

Year	Date	R&D Organization	Designer	Design Object
1945	Dec.	NII-1	Liul´ka	Turbojet
1945	Dec.	TsIAM	Kholshchevnikov Fadeev	Hybrid jet engine
1945	Dec.	TsIAM	Tolstov	Hybrid jet engine
1945	Dec.	TsIAM	Uvarov	Turboprop
1946	Jan. 5	…	Glushko	Three-chamber liquid-fuel rocket
1946	Jan. 5	NII-1	Isaev	Single-chamber liquid-fuel rocket
1946	Jan. 5	NII-1	Dushkin	Single-chamber liquid-fuel rocket Two-chamber liquid-fuel rocket
1946	Jan. 5	NII-1	Liul´ka	Turbojet
1946	Jan. 5	TsIAM	Kholshchevnikov Fadeev	Hybrid jet engine
1946	Jan. 5	TsIAM	Tolstov	Hybrid jet engine
1946	Jan. 5	TsIAM	Uvarov	Turboprop

Sources: GARF, 9401/2/65, 385; RGAE, 7516/1/309, 15; RGAE, 7516/1/318, 42-56; RGAE, 7516/1/319, 1-36; RGAE, 8044/1/460, 59, 104; RGAE, 8044/1/613, 172; RGAE, 8044/1/817, 18; RGAE, 8044/1/829, 235-242; RGAE, 8044/1/984, 253-258; RGAE, 8044/1/985, 73-76; RGAE, 8044/1/994, 21-23; RGAE, 8044/1/1182, 77-78, 81-84; RGAE, 8044/1/1321, 59-66, 233-235, 228-30; RGAE, 8044/1/1496, 317-323; RGAE, 8044/1/1496, 274-284; RGAE, 8159/1/6, 74; RGAE, 8159/1/137, 2-28; RGAE, 8159/1/140, 12-15; RGAE, 8162/1/89, 101; RGAE, 8162/1/240, 55-58; RGAE, 8162/1/300, 65-66, 80-81; RGAE, 8162/1/448, 7, 9; RGAE, 8162/1/449, 16-20, 96-7, 180-1; RGAE, 8162/1/574, 20, 24-26, 38-40, 85, 101; RGAE, 8328/1/696, 25, 133; RGAE, 8328/1/824, 1-50; RGAE, 8328/1/919, 84; RGAE, 8328/1/992, 6-7; RGAE, 8328/1/995, 106; RGAE, 8328/1/996, 16-18, 22-23ob; RGVA, 34272/1/167, 23-24, 47-55, 102-119; RGVA, 4/14/1171, 33, 36; RGVA, 4/14/1925, 21; RGVA, 4/14/2800, 4.

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RGVA (Rossiiskii Gosudarstvennyi Voennyi Arkhiv): Russian State Military Archive, Moscow

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Table 1. Major Soviet R&D Jet Propulsion Projects for Aviation, 1932 to 1946

	1932	1933	1934	1935	1936	1937	1938	1939	1940	1941(1)	1941(2)	1942	1943	1944	1945	1946
Rocket Motors																
Smaller Glushko rocket motors and aviation boosters	GDL	→	RNII	→	→	NII-3	→					KB Z-16	→	→	→	→
Large Glushko rocket motor leading to RP-218 aircraft					RNII	NII-3										
KB-7 rocket motor								KB-7								
Dushkin, Isaev rocket motors leading to RP-318 and BI fighter								NII-3, OSK Z-1	→	NII-3	→	GIRT, OKB-293	→	NII-1		
NII-3 rocket booster											NII-3	GIRT				
Dushkin rocket motors															NII-1	→
Jet Engines																
VTI gas turbine	VTI															
MAI gas turbine			MAI													
Uvarov gas turbines leading to turboprop engine					VTI	→	→	→		TsIAM	→		TsIAM	→	→	→
KB-7 ramjet							KB-7									
Liul´ka turbojet								TsKTI, Z-18	SKB-1	→	→	OKB-293	OKB-293, TsIAM	NII-1	→	→
Pobedonostsev, Merkulov ramjet	GIRD	→	RNII	→	→	NII-3	→	NII-3, TsKTI, OSK Z-1, Z-18	NII-3, OSK Z-1	→	→	GIRT	Z-84			
NII-3 hybrid jet								NII-3	→	→	→	GIRT				
Bas-Dubov, Zaslavskii ramjet										Z-28	→					
Abramovich hybrid jet													TsAGI			
Fadeev, Kholshchevnikov hybrid jet														TsIAM	→	→
Tolstov hybrid jet														TsIAM	→	→

Sources for Table 1: the Appendix, supplemented by Egorov (1994, pp. 424-36). The documentation supporting the Appendix comprises plans, reports, and memoranda of the ministries of defence, internal affairs, heavy industry, the defence industry, ammunition, and the aircraft industry.

Table 2. Soviet Jet Propulsion R&D Organizations and Their Fundholders, 1932-1946

Acronym	R&D Organization	Fundholder		Period Involved	Location	Notes
GDL*	Gas Dynamics Laboratory	Red Army Administration for Military Inventions	**A**	To 1934	Leningrad	Merged with GIRD into RNII in 1934
GIRD*	Jet Propulsion Study Group	Society for Cooperation in Air and Chemical Defence; transferred to Red Army Administration for Military Inventions in 1933	**A**	To 1934	Moscow	Merged with GDL into RNII in 1934
GIRT*	State Institute for Jet Propulsion Technology	USSR Council of People's Commissars	**D**	1942 to 1944	Moscow	Formerly NII-3
KB Z-16	Factory no. 16 Design Bureau	NKVD Fourth Special Department	**D**	From 1942	Kazan´	
KB-7*	Design Bureau no. 7	Red Army Administration for Military Inventions, then Artillery Administration; transferred to Defence (later Ammunition) Industry in 1938.	**A**	1938 and 1939	Moscow	Spin-off from RNII in 1935
MAI	Moscow Aviation Institute	Heavy (later Defence, later Aircraft) Industry**	**I**	1934	Moscow	
NII-1*	Research Institute no. 1	Aircraft Industry	**I**	From 1944	Moscow	Formerly NIIRA
NII-3*	Research Institute no. 3	Defence (later Ammunition) Industry**	**I**	1937 to 1942	Moscow	Formerly RNII
NIIRA*	Research Institute for Jet-Propelled Aviation	Aircraft Industry	**I**	1944	Moscow	Formerly NII-3
OKB-293*	Experimental design bureau no. 293	Aircraft Industry	**I**	1942 to 1944	Khimki, Moscow district; evacuated temporarily to Bilimbai, Sverdlovsk district, October 1941 to January 1942	Merged into NIIRA-NII-1 in 1944
OSK Z-1	Factory no. 1 Department of Special-Purpose Designs	Aircraft Industry	**I**	1939 to 1942	Moscow	
RNII*	Jet-Propulsion Research Institute	Heavy (later Defence, later Aircraft) Industry**	**I**	1934 to 1937	Moscow	Formed by GDL and GIRD in 1934
SKB-1	Special-Purpose Design Bureau	Defence (later Aircraft) Industry**	**I**	1940 to 1941	Leningrad	

Acronym	R&D Organization	Fundholder		Period Involved	Location	Notes
TsAGI	Central Aero-Hydrodynamic Institute	Aircraft Industry	**I**	1943	Stakhanovo (later Zhukovskii), Moscow district, evacuated temporarily to Kazan´ and Novosibirsk, 1941 to 1942	
TsIAM	Central Institute for Aeroengine Building	Aircraft Industry	**I**	1941 and from 1943	Moscow	
TsKTI	Central Boiler and Turbine Institute	Electricity Generation Industry	**I**	1939	Leningrad, with a subsidiary in Podol´sk, Moscow district	
VTI	Dzerzhinskii All-Union Thermal-Technical Institute	Electricity Generation Industry	**I**	1932 and 1936 to 1939	Moscow, evacuated temporarily to Keremovo, 1941 to 1943	
Z-18	Factory no. 18	Defence (later Aircraft) Industry**	**I**	1939	Voronezh, evacuated to Kuibyshev in October 1941	
Z-28	Factory no. 28	Defence (later Aircraft) Industry**	**I**	1941	Moscow, evacuated to Sverdlovsk in October 1941	
Z-84	Factory no. 84	Defence (later Aircraft) Industry**	**I**	1943	Khimki, near Moscow, evacuated to Tashkent in October 1941	

Key: **A** (Army); **D** (Dictator); **I** (Industry).

Sources: As Table 1 and Figure 1.
Note:
* See Figure 1.
** On December 8, 1936 the ministry of heavy industry was divided into a number of specialized branches of which one was the defence industry; on January 11, 1939 the ministry of the defence industry was divided into new ministries of the aircraft, ammunition, armament, and shipbuilding industries.

Table 3. RNII-NII-3, 1935 to 1941: Personnel by Employment Status and Gross Value of Output

	1935	1936	1937 plan	1938	1939	1940	1941 plan
Persons employed, annual average							
Engineering & technical employees	…	102	118	…	…	…	215
Manual employees	…	196	295	…	…	…	385
Nonmanual employees	76	84	88	…	…	…	…
accounting & clerical	…	…	…	…	…	…	125
production & planning	…	…	…	…	…	…	79
Junior service personnel	37	64	63	…	…	…	32
Total	403	446	476	514	799	…	836
Gross value of output, thousand rubles	…	3 377	4 482	6 111	11 434	11 233	…

Source: Employment: 1935 from RGAE, 8162/1/16, 16, and 1936-7 from ibid., 4 (no date but about February 1937); 1938-9 from RGAE, 8162/1/240, 32 (January 13, 1940); 1941 from RGAE, 8162/1/449, 144 (November 18, 1941). Gross value of output: for 1936 and 1937 plan see RGAE, 8162/1/16, 2-3 (February 28, 1937), for 1938-9 RGAE, 8162/1/240, 32 (January 13, 1940), and for 1940 RGAE, 8162/1/449, 3 (January 14, 1941). The figure for 1940 that had been planned and approved by KO was slightly higher at 11,725 thousand rubles. However, towards the end of that year an investigation disclosed that the responsible fourth chief administration of the ministry of the aircraft industry had illegally planned a much higher figure of 13,162 thousand rubles; see RGAE, 7516/1/692, 3 (November 21, 1940).

Table 4. Research Institutes and Design Bureaux of the Thirteenth Chief Administration of the Ministry of Defence Industry, 1938

	Budget, thou. rubles	Planned research topics	Scientific workers employed
NII-24	12 764	178	60
Leningrad filial	11 052	81	55
KB-47	8 006	94	55
NII-3	5 667	39	44
KB-7	1 200	9	13
KB-31	700	6	19
Total	39 389	407	246

Source: RGAE, 8162/1/299, 9 (no date but 1938). The thirteenth chief administration of the ministry of defence industry was the future ministry of the ammunition industry

Table 5. Major Directives of the Soviet Government Concerning Jet Propulsion, 1932 to 1944

Date	Issuing Authority	Decision
July 1932	Government Defence Commission	Expand research on jet propulsion
Sept. 1933	Council of Labour and Defence	Establish RNII
July 1940	Government Defence Committee	Develop the Liul´ka turbojet
Aug. 1941	State Defence Committee (the war cabinet)	Develop the BI (Berezniak-Isaev) rocket fighter
Nov. 1942	State Defence Committee	Produce the 302 (Kostikov) rocket fighter
Feb. 1944	State Defence Committee	Reorganize NII-1 as a research institute of the aviation industry
May 1944	State Defence Committee	Develop a number of rocket and jet aircraft and engines

Source: Danilov (1981, p. 71).

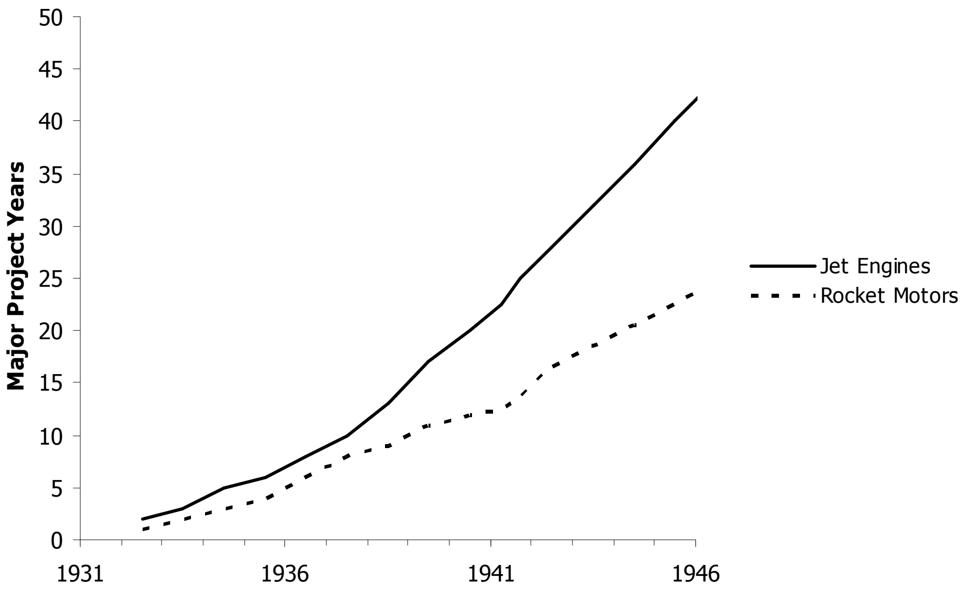
Table 6. Planned Funding of NII-3, 1940.

Source of funding	Number of projects	Thousand rubles
State budget	18	5 790
Contracts	15	3 440
Chief administration	12	2 495
Total	45	11 725

Source: RGAE, 8162/1/449, 3 (January 14, 1941).

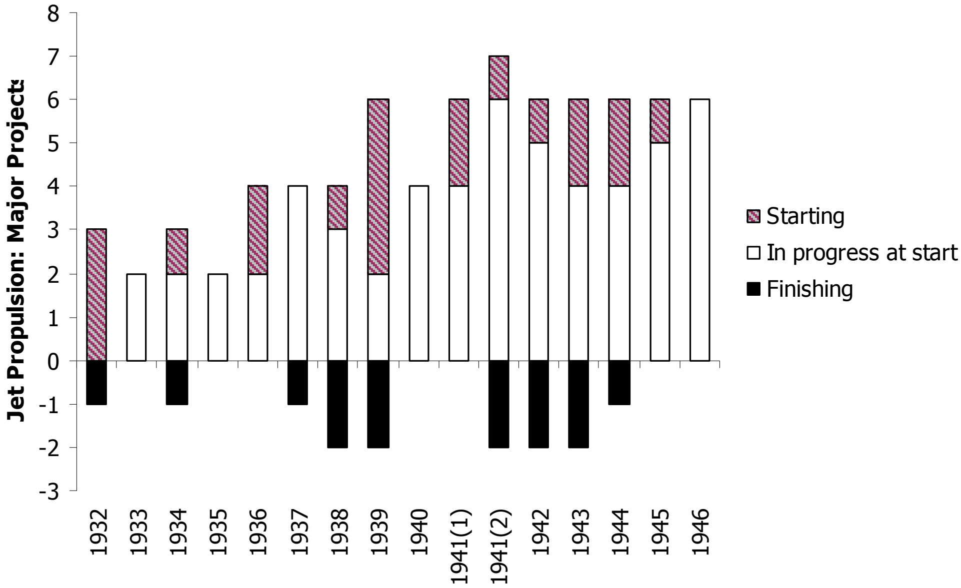
Figures

Figure 1. Soviet R&D in Jet Propulsion, 1932 to 1946: Cumulative Investment in Major Project Years



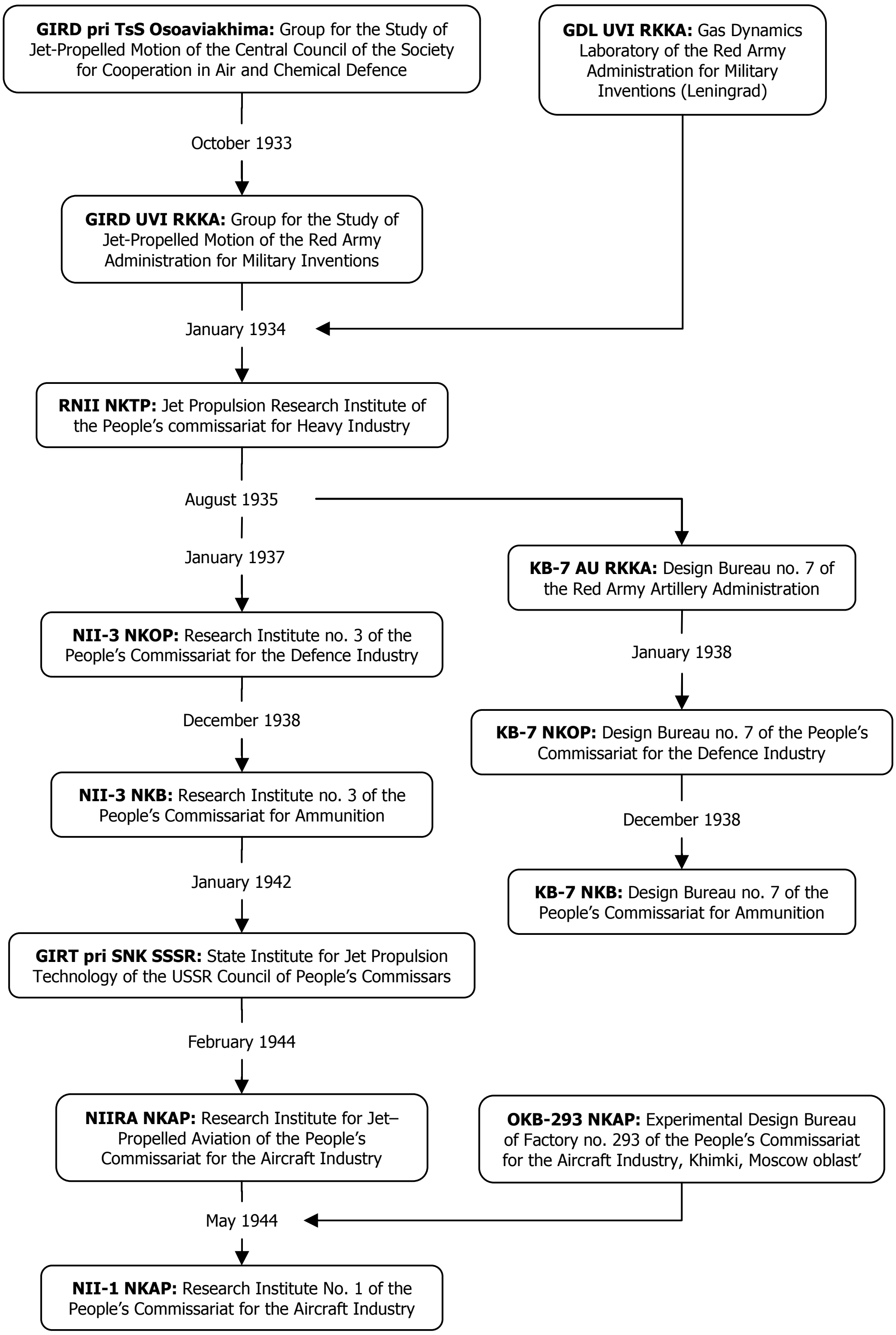
Source: Table 1.

Figure 2. Soviet R&D in Jet Propulsion, 1932 to 1946: Major Projects, Total



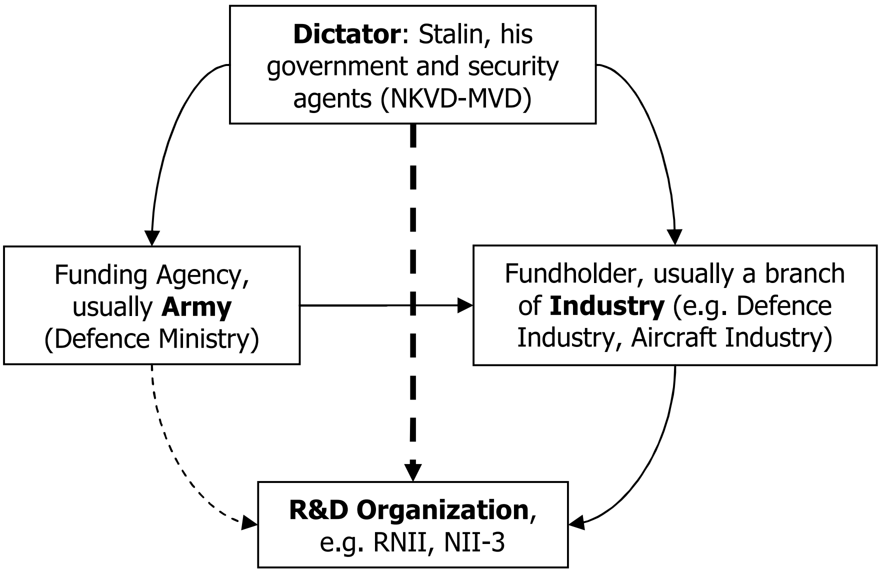
Source: Table 1.

Figure 3. The Evolutionary Path of RNII, 1932 to 1944



Sources and notes to Figure 3: For many details see Siddiqi (2000, pp. 1-18). In addition:GIRD, originally sponsored by Osoaviakhim, was taken over by the Red Army administration for military inventions in October 1933 before being merged with GDL, renamed RNII, and transferred to the ministry of heavy industry (RGVA 4/14/1171, 33: memorandum dated 23 January 1934). Siddiqi states that NII-3 was handed over to the ministry of the ammunition industry in November 1937, but this ministry was only created on the dissolution of the ministry of defence industry on 11 January 1939. Various documents indicate that the of the ammunition industry also acquired KB-7 from the Red Army's artillery administration at the beginning of 1938. A memorandum from deputy defence minister Fed´ko to prime minister Molotov dated 15 February 1938 refers to "the former KB no. 7 of the AU RKKA [Red Army artillery administration], transferred to NKOP [people's commissariat of the defence industry]" (RGVA, 4/14/1925, 22), and KB-7 is listed among the establishments of the thirteenth chief administration of the ministry of the ammunition industry in its report of work for the year 1938 (RGAE, 8162/1/89, 101). KB-7 was apparently dissolved in 1939. GIRT is described as "pri SNK SSSR [attached to the USSR Council of People's Commissars]" in its deed of transfer to the ministry of the aircraft industry, not dated but in 1944 (RGAE, 8044/1/1182, 11-16).

Figure 4. Players in the Quasi-Market for Inventions



Key

Funder contracts with fundholder.

Funder substitutes for fundholder.

Dictator substitutes for fundholder.

Endnotes

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[2] RGAE, *fond* 7516, *opis´* 1, *delo* 324, folios 6-11 (hereafter 7516/1/324, 6-11) (no date but 1939).

[3] RGAE, 8328/1/995, 111 (December 9, 1938): emphasis added. The prototype was an Uvarov gas turbine (see Table 1).

[4] RGAE, 8044/1/1182, 147 (July 26, 1944).

[5] RGAE, 8159/1/6, 74 (December 1936).

[6] RGAE, 8162/1/300, 65-66, 80-81 (November 17, 1940).

[7] RGAE, 8044/1/460, 59 (February 5, 1941)

[8] RGAE, 8162/1/574, 101 (May 7, 1942).

[9] In November 1929 the post of chief of armament of the Red Army was created to help carry through its equipment modernization. The first chief of armament was Army Commander Uborevich, followed in 1931 by Army Commander, later Marshal Tukhachevskii. Among the departments reporting to the chief of armament was an administration for military inventions. In 1936 the post of chief of armament was abolished, its place taken by a chief administration for supply of weapons and equipment, and under the latter a department for inventions (see Holloway, 1982a, p. 321). On Tukhachevskii and Red Army rearmament generally see Samuelson (1996 and 2000) and Stoecker (1998).

[10] GARF, 8418/6/243, 35-37 (May 14, 1933).

[11] RGVA, 4/14/1171, 33 (January 23, 1934); also Siddiqi (2000a, pp. 4-7).

[12] RGVA, 34272/1/146, 134 (October 31, 1933).

[13] RGVA, 34272/1/177, 5-10 (May 27, 1934), 17-19 (May 29, 1934), 20-21 (June 1934), 1-2 (July 26, 1934), and 33 (September 13, 1934); also Siddiqi (2000a, pp. 7-9; 2000b).

[14] RGAE, 8044/1/984, 264-275 (October 22, 1943).

[15] RGVA, 29/56/349 (1932-1936).

[16] RGVA, 29/56/354 (1937).

[17] RGVA, 34272/1/146, 145 (November 16, 1933).

[18] GARF, 8418/6/243, 42 (August 22, 1933).

[19] RGVA, 34272/1/146, 28-39 (no date but 1932).

[20] RGVA, 34272/1/105, 91-94ob (May 20, 1931).

[21] RGVA, 34272/1/105, 118-120 (May 1931).

[22] RGAE, 8159/1/149, 220 (July 26, 1936), 219 (September 29, 1936) and 218 (October 13, 1936).

[23] The reference was to *Revista Maritima*, 1936, no. 6, 421-439; see RGAE, 7516/1/324, 12-42, for the translation. The article was mainly about rocket artillery; it raised possible applications to aviation on the last page.

[24] RGAE, 7516/1/324, 1-4 (April 9, 1939).

[25] RGAE, 8162/1/305, 30 (April 16, 1940).

[26] RGAE, 7516/1/324, 10 (no date but 1939).

[27] RGAE, 7516/1/323, 1-18 (no date but 1939), translates “What Can We Expect of Rockets?” by Major James Randolph of the US Army artillery reserve, published in *Army Ordnance* 19(112), Jan.-Feb. 1939, 225 ff.

[28] RGAE, 8044/1/1182, 123-147 (July 28, 1944).

[29] RGVA, 29/38/96, 1-479 (June 10, 1936).

[30] RGAE, 8044/1/359, 1-187 (September 27, 1940); 8044/1/358, 1-9 (September 29, 1940).

[31] For example RGAE, 8159/1/137, 2-28 (no date but 1937), 8162/1/240, 9-63 (January 9, 1940), and 8162/1/449, 2-61 (January 14, 1941) for the annual reports of RNII-NII-3 in 1936, 1939, and 1940 respectively. In 1967 the annual reports for 1937 and 1938 were transferred from RGAE to the archive of the USSR Academy of Sciences where they can no longer be traced. I thank Leonid Borodkin for looking.

[32] RGVA, 29/56/361 (1937 to 1940).

[33] RGVA, 4/14/1628, 123-128 (June 15, 1937). Kleimenov had a history of personal conflict with Tukhachevskii’s subordinates which might have helped him; see for examples RGVA, 34272/1/177, 1-2 (July 26, 1934) and 33 (September 13, 1934). But he was isolated by Ordzhonikidze’s suicide.

[34] RGAE, 8162/1/89, 125 (no date but 1939).

[35] RGAE, 8162/1/299, 36-54 (March to April 1939). Commissar Sergeev was unconnected with engineer Sergeev mentioned above.

[36] RGVA, 34272/1/177, 5-10 (Korneev to the Okt´iabrskii party raikom, May 27, 1934), and 17-19 (Korolev to Tukhachevskii, May 29, 1934).

[37] RGAE, 8044/1/817, 19-25 (Liul´ka to Stalin, May 18, 1942). Stalin took it up with Malenkov who took it up with Shakhurin (Berne, Perov, 1998, p. 86). Liul´ka's group was absorbed into OKB-293 in July 1942 (RGAE, 8044/1/817, 18 (August 10, 1942).

[38] RGAE, 8044/1/460, 49-51 (December 31, 1940): an explanatory memorandum by People's Commissar for the Aircraft Industry A.I. Shakhurin on the 1941 plan for aeroengineering research and experimentation.

[39] RGVA, 4/14/1925, 16-18 and RGAE, 7515/1/378, 304-306 (both December 31, 1937).

[40] RGAE, 7515/1/378, 298-303 (no date).

[41] RGVA, 4/14/1925, 21-21ob (February 4, 1938) and 4/14/1925, 22-22ob (February 15, 1938).

[42] RGAE, 8044/1/460, 60-57 (February 5, 1941).

[43] RGAE, 8044/1/1342, 17 and 21 (March 1, 1946).

[44] RGAE, 8044/1/1342, 7 (March 1, 1946).

[45] RGAE, 8044/1/1342, 31 (March 1, 1946).

[46] RGAE, 8044/1/1318, 21, 22 (1945). This file contains the materials for a report by the Commission for Study and Assimilation of German Jet Propulsion Technology headed by headed by minister for the aircraft industry Shakhurin.

[47] RGAE, 8044/1/1496, 317-323 (December 1945) and 274-284 (January 5, 1946).

[48] RGAE, 8044/1/1637, 230-5 (July 15, 1947).

[49] RGAE, 8162/1/449, 87 (April 10, 1941).

[50] RGAE, 8044/1/3079, 82-91 (August 27, 1946).

[51] RGAE, 7516/1/692, 3 (November 21, 1940).

[52] Transitions: to mark the transformation of GIRD into RNII, and in light of their achievements including the first Soviet liquid fuelled rocket, chief of the Red Army admistration for military inventions Terent´ev asked Tukhachevskii to set aside 2,500 rubles to be distributed among the GIRDers as bonuses (RGVA, 34272/1/146, 145:

November 16, 1933). Achievements: to mark the successful exploitation of its rocket shells in combat against Japan and Finland, NII-3 director Slonimer asked ammunition minister Sergeev to decorate his most outstanding staff, not named (RGAE, 8162/1/306, 186-187: July 22, 1940). This request then became evidence in the charges subsequently levelled against him that I describe in the text. Anniversaries: in relation to the tenth anniversary of the prison design bureau OKB-172 armament minister Ustinov and NKVD chief Kruglov wrote to Stalin to request that he award commemorative decorations to the former "enemies of the people" working in it (GARF, 9401/2/170, 213-228: July 13, 1947).

[53] RGAE, 7515/1/379, 134-137 (April 19, 1938).

[54] RGAE, 7516/1/692, 1-7 (November 21, 1940).

[55] RGAE, 8044/1/1795, 94 (March 26, 1948).

[56] Stalin Prizes for 1947: RGAE, 8044/1/1962, 94 (March 31, 1948). Prize money, RGAE, 8044/1/1795, 79 (no date but April 1948). Stalin Prizes for 1948 RGAE, 8044/1/1965, 7 (no date but March 1949).