THE POLITICAL ECONOMY OF A SOVIET MILITARY R& D FAILURE: STEAM POWER FOR AVIATION, 1932 TO 1939

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Abstract

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Acknowledgements

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Introduction

The Soviet economy was managed by a vertical hierarchy in which agents supplied principals with flows of information from below and principals issued commands from above. Commands flowed downward, but the more closely we study this system the more we find that self–interested agents rarely did exactly as they were told. Some horizontal transactions among agents that were ordered did not take place, and others took place without being ordered or even when they were prohibited. Information flowed upwards but the most difficult problem for those who received it was to verify exactly what people were really doing when they appeared to be obeying commands.

In this paper I explore the relationship between the Soviet vertical command hierarchy and the horizontal interactions of agents through the prism of an R&D failure. This was the Soviet attempt to create a new aeroengine technology using steam power. It was a serious venture that consumed significant resources for a few years and provides a relatively self–contained episode for studying the motivations and calculations that drove the R&D process.

What is an R&D failure? All research may produce new knowledge of both explicit and tacit kinds, and generates externalities that are potentially of benefit to society. In this paper I define failure narrowly within a principal–agent framework: an R&D project fails even though it yields a return to society, if it does not generate a surplus for the funding principal from the useful application that the principal intended. Thus I will classify Soviet investment in steam power for aviation as an

This draft 31 October, 2001.

R&D failure even though it may have enhanced human knowledge and generated all sorts of useful spinoffs.

The economic significance of R&D failures can be considered from three perspectives. R&D failure may be analysed within a profit–seeking framework as a cost to an economic principal, within a rent–seeking framework as consumption by an economic agent, and within a political economy framework as a channel through which a political principal may distribute rewards to loyal agents.

In considering R&D as a profit–seeking activity it is useful to distinguish the structure of competition between and within nations. In general R&D can be motivated by both "profit" and "competitive threat".[1] From a national perspective each country pursued its defence objectives as a strategic competitor in relation to other nations. Military technologies provided the means to these objectives, and investments in military R&D made the technologies more efficient. By investing in technological enhancement each nation could expect to realise its strategic goals at less cost when the military technology of other states were controlled, i.e. even if others did not engage in military R&D. This is the profit motive. The second motive arose from knowing that its rivals were also engaging in military R&D: the nation that fell behind might fail to maintain its strategic position and be beaten, i.e. lose ownership rights over its assets to a competitor. This motive is the competitive threat.

The dimension of competitive threat gave the process of interwar military R&D its character of a technological race between the great powers. At the same time competitive threat did not overwhelm the profit motive. If it had, a nation that fell behind the leader would have lost any incentive to invest in trying to come second. In military aeroengineering we see that each great power invested substantial resources in those areas where it was not the technological leader; it was an R&D success to come first, but it was not a failure to come second or third; it was only a failure to come nowhere. One reason for this is that the decisive advances came too late in the war to be decisive in combat. Another reason is that some of the new knowledge produced by R&D did not become common knowledge because a part was kept secret, and some of the rest remained tacit and could only be acquired through "learning by doing".[2] Thus, Germany was the first power to create jet aircraft, and was able to exploit an advantage over its enemies as a result, but the British and Russians rationally maintained their efforts to come next.

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[1] For this distinction see Beath, Katsoulacos and Ulph (1995).

[2] On tacit knowledge see MacKenzie (1996), 215–16, and on learning by doing Arrow (1962).

The structure of competition within each country created the same motivations in a different balance. Within the British, German, and Soviet markets for military invention individual agents also faced a profit motive and a competitive threat. Think of the returns to R&D success as partly financial and partly reputational. In terms of reputation the *only* thing that mattered was to come first: for example each country now remembers its own pioneer of the jet aeroengine, Frank Whittle, Hans von Ohain, and A.M. Liul'ka, while their rivals are completely forgotten. Much more than between countries, the competition within each country took the form of a race into which each rival was drawn by the chance to scoop the winnings before the others.

Other than in terms of reputation, none of the jet pioneers was allowed to make a profit from realising their dream. In Britain the first contracts for serial production of jet engines were given to Rolls Royce, deliberately sidelining Whittle's company Power Jets, and in Germany to Junkers and BMW, favouring the rivals of Ohain's sponsor Otto Heinkel. For different reasons Soviet arrangements gave designers no expectation of a stake in the producer profits arising from their inventions. This might even have been a good thing in so far as the combination of a limited pool of potential inventions with winner–takes–all may lead rival agents to invest in R&D until all the potential gains have been competed away.[3]

The approach outlined so far treats investments in military R&D as a cost to a profit–seeking principal. Since R&D outcomes were uncertain there were many potential projects each with a high probability of individual failure. Principals had to be willing to fund many projects in order to ensure that at least some successful projects would be included. Thus, failed inventions were part of the cost of success.[4]

Within a rent–seeking framework military R&D is not only an investment cost to the principal but also a source of the agent's consumption. Therefore, military R&D may become a focus for self–interested rent–seekers. Several factors encourage it: the cloak of military secrecy; relatively soft budget constraints; intrinsic uncertainty about the timescale and expected value of returns to investment that impede selection, including the rational expectation that many projects will fail; and large information biases that impede monitoring. Under these circumstances R&D agents can be expected to invest resources in lobbying to win project funding, and some of the resources they invest will be diverted from nominal allocations to military R&D.

Thus R&D failures may have another significance. From the point of view of the principal R&D failures were simply part of the cost of success: some experiments

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[3] Dasgupta and Stiglitz (1980).

[4] Mokyr (1990), 176–7.

fail, and failed experiments are part of the necessary background against which success is achieved. In contrast, from the point of view of rent–seeking agents unsuccessful projects provided consumption nearly as effectively as successful ones. From this perspective R&D failures may be a gain to the agent although a loss to the principal. Why then should agents pursue success for the principal? Agents' indifference to failure might also be strengthened if reputational capital created by past success could not be translated into higher income.

Finally, within a political economy framework, in the presence of rent–seeking a political principal such as a dictator may deliberately design the allocation system to enable transactions in the political market place, for example to distribute gifts to agents in return for loyalty. For example, in a study of Soviet regional policy James Harris has shown that Stalin used investment allocations to reward loyal agents in the regions in his struggle with the opposition in the late 1920s; during the 1930s, however, his regional agents were called to account for their uses of these resources.[5] Valery Lazarev and Paul R. Gregory have shown in a detailed study of the Soviet allocation system for motor vehicles in the 1930s that the dictator maintained a stock of vehicles in reserve for use as rewards for loyal agents.[6]

If the budgetary system is used to reward loyal agents, the effect must be that budgetary outlays will exceed an efficient level. The excess is the signal that loyalty is expected in return: if some waste did not result, those receiving the funding would have no reason to offer thanks to the government in exchange since any politician would rationally promise to undertake at least those expenditures that were efficient.[7] If the system for military procurement and R&D were used in this way, then some R&D failures might be the intended outcome of a political exchange through which both agent and principal gained: the agent gained consumption and the principal gained loyalty, which is one source of political power.

In short, the incidence of R&D failures may reflect an economic experimentation process in which a certain proportion of failures is an unintended but necessary consequence, or it may reflect an economic process in which opportunistic agents extract rents from a funding principal, or it may reflect an intention on the part of a political principal to compensate agents directly for their loyalty. To discriminate between these hypotheses in the case of Soviet military R&D requires a close study of the decision making process, and this is one purpose of the analysis that follows.

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[5] Harris (1999).

[6] Lazarev and Gregory (2000).

[7] Wintrobe (1998), 31.

I explore this process through the documentary records of the Soviet 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), both in Moscow. The paper is in five parts. Part 1 sets the idea of aviation steam power in the context of early twentieth century aeroengineering. Part 2 outlines the dimensions of the Soviet R&D effort in this field in the 1930s. Part 3 describes the vertical and horizontal relationships within which decisions were taken to initiate and continue or terminate projects, and part 4 sets out the options open to agents to mount and resist competitive threats to and from each other. Part 5 analyses the problem faced by the funding principals in distinguishing between good and bad projects. Part 6 concludes.

1. Problems and Solutions

In the interwar period aircraft performance neared the limits of the traditional propulsion technology, the reciprocating piston engine driving an airscrew propeller.[8] The mechanical efficiency of propellers was found to fall away beyond a point as rotation speeds increased, with the result that propeller–driven aircraft could never approach supersonic speeds or stratospheric altitudes. Piston engines also required frequent and intensive maintenance and had short service lives. Such limitations prompted intensive efforts in several European countries to develop completely new types of aeroengine based on a continuous thermal cycle giving rise to a jet reaction. In Great Britain, Germany, and the Soviet Union much effort was invested in two alternatives: the rocket motor and the jet engine.[9]

The rocket principle had been well understood for hundreds of years, and European armies had used small, solid–fuelled rockets on the battlefield since the Napoleonic era. The new fuels and heat–resistant materials being developed in the early twentieth century promised significant applications for the rocket principle in aviation propulsion. However, to create a primary rocket motor for aviation still implied a design of unprecedented size and complexity by interwar standards, depending on more powerful liquid fuels with substantial further advances in material and fuel sciences and control systems. At the end of the development process lay apparatuses that could attain extraordinary speeds and limitless altitudes but with fuel consumption at rates that limited powered flight to a few minutes' duration.

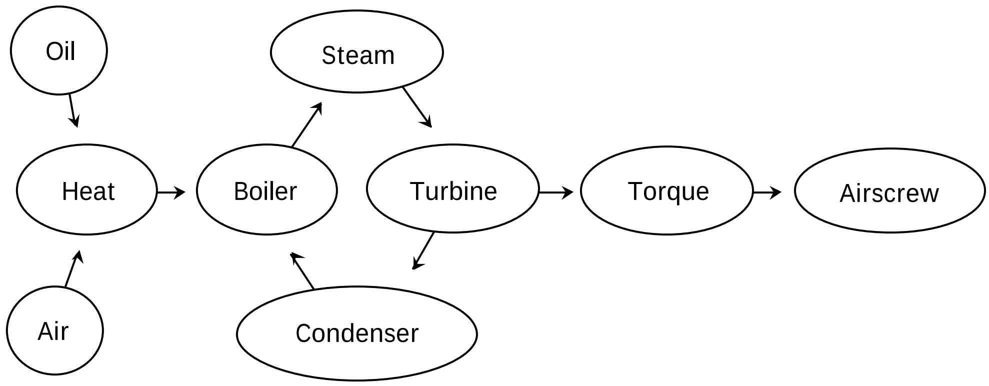
[8] Grigor'ev (1994), 189.

[9] Soviet rocketry before and during World War II has been investigated by Ordway and Sharpe (1979), Holloway (1982b), Siddiqi (2000) and, with the benefit of new archival documentation, Harrison (2000). On the early development of the Soviet jet aeroengine see Harrison (2001).

The concept of the jet engine was of more recent origin. Earlier designs could not provide a primary power plant because they could not be ignited unless the aircraft was already moving at flight speed. Later designs such as the turbojet made this defect good at the cost of added complexity including moving parts rotating at very high speeds and temperatures; these could not be brought into reality without still greater advances on interwar benchmarks in terms of heat–resistant alloys, fuels, and the control of combustion.

Hindsight tells us that by the end of World War II the turbojet would solve the problem of high–speed, high–altitude aviation. Liquid–fuelled rocketry, although not the answer for aviation, would solve other problems of strategic bombardment and space travel. During the interwar period this outcome was not yet clear and several avenues that would later be seen as stopgaps or failures were also explored. One of these was the attempt to build a steam–driven propulsion unit for Soviet aviation.

Figure 1. The Steam Turbine in an Aviation Propulsion Unit



The basic scheme of a steam–powered aeroengine is shown in figure 1. It involved an oil–fired boiler to create steam; expansion of the steam in a turbine converted part of its thermal energy into kinetic energy that initially took the form of the torque required to rotate an airscrew propeller; the propeller drove an airstream backwards and the aircraft forwards. Since the aircraft in flight could not replace its water, the steam passed through a condenser before being returned to the boiler in a closed circuit. Additional refinements could include: using a multi–stage turbine to convert more of the overall steam pressure drop into useful energy; expanding the boiler's exhaust gases in a gas turbine to supercharge the boiler itself or to supplement the torque delivered to the propeller; using the heat otherwise lost from the condensing steam to expand the cooling air in such a way as to add to the overall thrust. At least one experimental Soviet design also introduced a mercury boiler so as to utilise its higher temperature limits as a preliminary stage to a steam turbine.[10]

Figure 2. Where the Steam Turbine Engine Fits

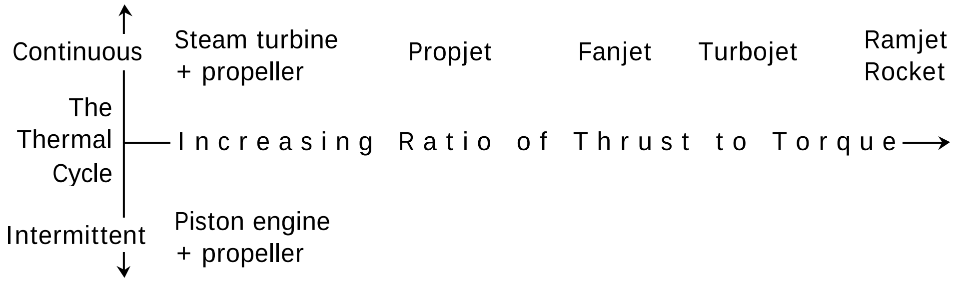


Figure 2 arranges the spectrum of modern aeroengines in two dimensions. Along the vertical axis the technologies of more recent development that make use of a continuous thermal cycle are demarcated from the traditional technology that relied on the intermittent action of reciprocating pistons. Along the horizontal axis the proportion of the energy that is delivered in the form of a jetstream, or thrust, rather than of torque to a propeller or turbine rises from zero to infinity.

The steam turbine lies at the most conservative extreme of the range of continuous thermal cycle engines, in that it aimed to deliver torque more efficiently rather than replace torque by thrust. This meant that the steam turbine, even if it worked, would never give access to supersonic speeds or stratospheric altitudes. Its main advantage lay in offering to replace the reciprocating engine with a continuous cycle using a familiar technology that operated reliably for long periods at moderate temperatures and rates of rotation using materials that were already available.

The concept of steam–driven propulsion for aircraft should appear surprising only in retrospect. In the interwar period steam turbines were widely used in naval propulsion, their other main use being in electric power generation. Historically the gas turbine came after the steam turbine and arose from the latter, so it was the steam turbine that was already the more proven technology.[11] Interest in steam power for aviation was by no means confined to the Soviet Union. A Soviet document of 1937 lists six European and two American engineering companies as involved in parallel developments.[12] A shorter list published by *Flight* magazine in wartime London

[10] The principle of the mercury boiler, first applied in the United States by General Electric in 1914, was evaluated briefly by Stodola (1927), 1313–16.

[11] Voronkov (1984), 115.

[12] RGAE, 8328/1/919, 77 (28 February 1937). The American companies were General Electric and Great Lakes Aircraft. Among the European companies AEG,

overlaps in part, identifying two American ventures and one British.[13] As will become apparent, it seems likely on present information that roughly as many aviation steam power projects were pursued in the Soviet Union as in the rest of the world put together at the time.

If steam turbines replaced the reciprocating engine at sea, then why not in the air as well? The main problem was that existing land– and ship–based applications of the steam turbine were based on ratios of power to weight and volume that were too low to take to the air. They required not only large boilers but also bulky condensers to convert steam back to water; these could scarcely be accommodated within an airframe light enough to be lifted into the air by the power that the turbine would develop.[14] Improving power relative to the mass of the engine and its fuel was therefore the main focus of aviation–related development efforts.

2. Scale and Scope

Table 1 provides an overview of the main Soviet R&D projects in aviation steam turbines from 1932 to 1939. It is compiled from plans, reports, and memoranda of the commissariats of defence, heavy industry, the defence industry, and the aircraft industry. The table shows that in the prewar years there were eleven major projects involving eleven research establishments; the association between projects and establishments was not very tidy since some designers had more than one institutional affiliation through time or even contemporaneously. This compares with perhaps ten projects in the rest of the world at the time. There were five main funding interests: the Red Army air force, the civil aviation authority, the Academy of Sciences, the aircraft industry, and the electricity generation industry. There were three urban centres of activity where four designers accounted for three fifths of the 34 project–

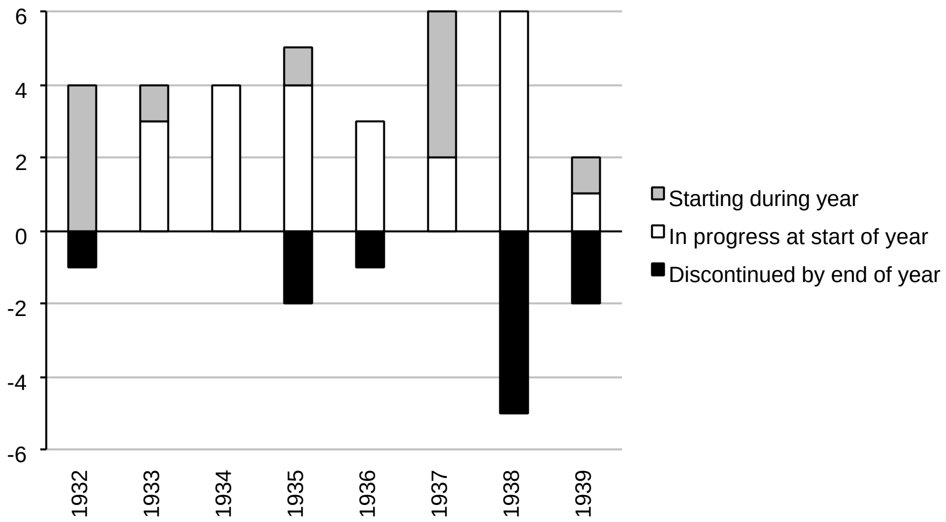
Wagner, and Hüttner were German, and the others (I translitterate them from cyrillic as Forkauf, Bessler, and Dobel') look German but have not been traced. Thanks to Jörg Baten and Mark Spörer for advice.

[13] Smith (no date), 36–40. This publication of approximately 1943 describes projects of Great Lakes Aircraft and United Aircraft (in the name of the helicopter pioneer Igor Sikorsky and others) in the United States and Aero Turbines in London, the work of the latter being based on the German Hüttner turbine. According to Smith, Breguet Aviation in France was known to be working on a reciprocating aeroengine supercharged by a steam turbine in 1942. Research on similar lines was carried out in the Soviet Union in the early 1930s at the Khar'kov Aviation Institute (KhAI) and under the Red Army Bureau of New Designs (BNK), but was evidently abandoned before long: see Rodionov (2001), 1932 under September (Sovnarkom decree on the construction of steam turbine engines), and 1933 under 17 January (Unshlikht to STO) and 23 March (Almazov to Gosplan).

[14] Liul'ka and Kuvshinnikov (1981), 88.

years in total: S.A. Aksiutin and N.M. Sinev in Moscow, P.L. Kozhevnikov in Leningrad, and V.T. Tsvetkov in Khar'kov.

Figure 3. Soviet Aviation–Related R&D in Steam Turbines, 1932 to 1939: Numbers of Major Projects



Source: calculated from table 2.

The time profile of these projects is illustrated in figure 3. Officially work began in 1932. Between then and the end of 1937 ten projects were initiated. Four of them had been curtailed already by the end of 1936, so the number of major projects in progress peaked at the end of 1937 at six. Five of those were cancelled during 1938 and, although one more was begun during 1939, all had been abandoned by 1940.

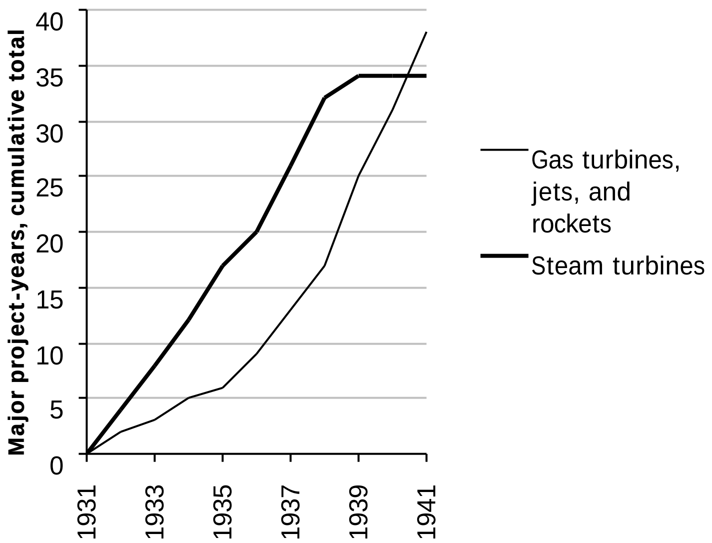
Did this effort represent a significant commitment of national resources? On the information available at present, the answer appears to be no. At the end of 1937, acting director Sinev of the special–purpose design bureau (SKB) of the commissariat of the defence industry put the total of sunk costs of the various steam turbine projects so far at 20 million rubles over five and a half years, i.e. not more than four million rubles per year.[15] On the basis of an annual average wage for that period of 3000 rubles, four million rubles would also represent the direct–plus–indirect employment of up to 1300 public–sector workers. Included in this total were a few scientists and designers who were more highly paid and also represented a particularly scarce resource, but even 100 such specialists would have represented no

[15] RGAE, 8328/1/992, 15 (19 December 1937).

more than one per thousand of the Soviet Union's population of "scientific workers" in 1940.[16]

Although insubstantial in absolute terms, the Soviet interwar effort in the direction of aviation steam power probably exceeded that directed towards the development of gas turbines, jets engines, and rockets for aviation. Table 2 shows that in every year between 1932 and 1938 at least as many and usually more steam turbine projects were in progress than the number of jet propulsion projects. Only in 1939 did efforts in jet propulsion begin to overshadow the steam turbine projects as the cull of the latter got under way. Consequently, as figure 4 shows, the cumulative investment of Soviet R&D resources in steam turbines, measured in major project–years, was overtaken by that in jet propulsion only in 1941.

Figure 4. Soviet Aviation–Related R&D in Steam Turbines Versus Gas Turbines, Jets, and Rockets, 1931 to 1941: Cumulative Investments in Major Project–Years



Source: calculated from table 2.

The technical variation among steam turbine project designs was considerable. Kozhevnikov's "gas–steam" apparatus evidently made use of the boiler's exhaust gases in an auxiliary turbine. Przheslavskii's "binary–cycle" turbine used a high–temperature liquid, probably mercury, in an auxiliary boiler. Design capacities ranged from a few hundred horse–power to Tsvetkov's first monster, rated at 15 000 horse–power but never built. By comparison, the largest reciprocating aeroengines in serial

[16] There were 98 300 "scientific workers" in the Soviet Union in 1940 according to Goskomstat (1987), 64.

production in the Soviet Union and elsewhere at the end of the 1930s somewhat exceeded 1000 horse–power.[17]

The performance characteristics that mattered most were specific weight and specific fuel consumption, both measured relative to capacity. These are not always reported in the documentation, but available figures are shown in table 3. Variation was considerable, but the typical design proposed a 3000 horse–power engine with a specific weight of 1 kilogramme per horse–power and specific fuel consumption around 300 grammes per horse–power per hour of operation.

The specific weight of the steam turbines was generally not as good as that of contemporary piston engines. For example, the design weight of the Mikulin M–34 mass–produced in the mid–1930s was 0.8 kilogrammes per horse–power.[18] Moreover, the specific weight of piston engines was falling. The M–34 and Klimov M–105, the Wright Cyclone and its Soviet derivative the M–25, and the Rolls Royce Merlin, all weighed in at 0.6 to 0.7 kilogrammes per horse–power in their last versions of the prewar period.[19]

Specific fuel consumption can also be compared, although comparison is complicated by the fact that piston engines burnt high–octane petroleum rather than the low–grade fuel oil used by a steam boiler.[20] In the mid–1930s the design consumption of the mass–produced M–34 in its RN and FN versions was 255 grammes of aviation spirit per horse–power per hour.[21] For a cross–check consider the reported performance data of the 1936 version of the four–engined TB–7 heavy bomber, the aircraft that some designers had in mind for a steam turbine: these imply a figure that was only slightly higher at 300 grammes per horse–power per hour.[22]

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[17] Other steam power aeroengine projects not considered here include plans to build a steam–turbine supercharger for a reciprocating aeroengine that were pursued in 1932–3 (see footnote 13), and a project to design a small (up to 120hp) aviation engine based on the motor of an imported steam automobile (see Rodionov, 2001, 1934 under 23 January).

[18] Rodionov (2001), 1934 under 3 July.

[19] Grigor'ev (1992), 86, 90, 93.

[20] According to Jasny (1952), 151–2, the official wholesale prices of fuel oil in Leningrad and of grade 2 motor petroleum in Moscow in 1937 were 155 and 900 rubles per ton respectively

[21] Rodionov (2001), 1934 under 14 July and 1936 under 5 July.

[22] The maximum range and speed of the TB–7 of 1936 are given by Gunston (1995), 280–1, as 3000 kilometres and 403 kilometres per hour at an altitude of 8000 metres, but no aircraft could achieve both at the same time. A cruising speed of 350kph would suggest a maximum flying time of 8 hours 35 minutes. The TB–7 of that time had four M–34FRN engines totalling 3600 nominal horse power but for

Table 3 suggests that the more fuel–efficient steam turbines were competitive with this. They also used a much cheaper and more readily available fuel, so regardless of specific fuel consumption they offered immediate gains in ruble operating costs.

Ultimately, however, the ruble cost of fuel required was a less important limit on performance than its weight. Lower running costs did not compensate for the sheer mass of steam turbine engines, including the mass of fuel. A TB–7 with its fuselage rearranged to accommodate boiler and turbine, and with condensers filling its wings, had little space remaining for fuel, crew, or payload.

3. Project Finance

3.1. Rationing, Rivalry, and Budget Constraints

What limited Soviet outlays on steam propulsion R&D? Stalin's Politburo set cash limits on ministerial budgets from year to year, but detailed allocation was delegated to officials at or below the level of minister. The main problem these officials faced was technological uncertainty: R&D agents presented them with many proposals for long–term projects, one of which would eventually solve the problem of aviation propulsion for the next half century, but no one knew which one. Rationing was an appropriate response. Funding was rationed across new projects, and was also rationed through time for established projects. As a result, R&D agents competed for both initial funding and subsequence refinancing. Making limited allocations to many projects permitted funding principals to exploit the rivalry of the agents and, by monitoring the progress of competing projects, to use each to provide information about the others and thus learn about their true worth.[23] And by rationing funding through time principals could monitor the cumulative progress of each project towards its goal so that subsequent refinancing decisions could be taken in the light of more information than was available initially.

Rationing across projects and through time carried important costs to the principal. Rationing through time had the effect of softening budget constraints on

cruising speed say 3200hp, making a maximum flight total of just over 27 400 horse–power hours. The TB–7 carried 8250 kilogrammes of fuel (Gunston, 1995, 280–1), making roughly 300 grammes of fuel consumed per horse–power per hour. Thanks to Keith Dexter for advice.

[23] Such competition was eventually normalised in Soviet aviation R&D: rival design bureaux were regularly assigned similar specifications by the government and competed for their designs to be adopted by the consumer, the defence ministry. See Berliner (1976), 126, Holloway (1982a), 317–19. An implication of the present study is that agents' rivalry was not "artificially" created by the principal; it was intrinsically present, and the principal could choose to suppress or exploit it.

individual projects because, in the presence of sunk costs, a project could attract refinancing even when it was known to be bad. Because some costs were already sunk, it could still be efficient for both the funding principal and the R&D agent to continue a project that the principal would have preferred not to finance in the first place.[24] Rationing across projects brought the danger of a fragmentation of effort in many rival projects, all underfunded. Both types of rationing invited agents to invest resources in lobbying to soften constraints and use the argument that costs have already been sunk as an argument for project continuation.

Financial constraints on projects in progress therefore tended to become soft, and occasionally this became explicit. At a meeting of the technical council of the chief administration for the aircraft industry held in August 1936 to review the development of a number of steam turbine projects, one of the designers present reported: “they told me [that] to carry out the testing of the turbine in our factory funds of the order of a million rubles [were] needed”. The presiding deputy minister for heavy industry M.M. Kaganovich interrupted: “I can provide it”. Kaganovich told another designer to proceed if he could to a flight test: “Whatever it costs I’ll pay”. He summed up:[25]

> I am not so poor, we have money in the sums that are needed, the boss is not hoarding it, comrade [G.K.] Ordzhonikidze [Kaganovich’s boss] says to take what you need.

What were the consequences of a soft budget constraint? The soft budget constraint might seem like a good thing for technical progress at first sight because the chances of successful invention would appear to increase with the number of generously funded projects. However, a soft budget constraint probably also encouraged adverse behavioural responses. Hanson and Pavitt have noted a tendency of government–funded R&D to generate “too few technical alternatives”; this is because, when budget constraints are soft, R&D agents display too little care in coming to conclusions. They “do not apply the normal, prudent practice of commercial firms in carefully exploring technical alternatives in order to reduce technical and commercial alternatives. Instead, they tend to follow a high risk strategy of premature commitment to the full scale commercial development of a particular technical configuration, before the reduction of key technical and

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[24] Dewatripont and Maskin (1995).

[25] RGAE, 8328/1/824, 40, 51, 52ob (22 August 1936). This was the brother of the more famous Politburo member and Stalin’s deputy L.M. Kaganovich.

commercial uncertainties".[26] In other words, uncertain outcomes are not a good reason to throw money at a problem.

Rationing and soft budget constraints help explain an institutional cycle that accompanied Soviet progress in new aeroegnineering technologies in the interwar years.[27] The first phase was one of exploration. For the first time the principal defined the mission and agents formed a lobby. As a result cash was allocated and initial funding was dispersed among agents. With first results, existing projects were refinanced and further projects were designated. At a certain point the principal lost patience with rising expenses and lack of results, and declared a need to concentrate efforts and focus them more narrowly. For example in August 1936 Kaganovich wrote to the Council for Labour and Defence (STO) with Ordzhonikidze's support to unify all work on steam and gas turbines under his chief administration for the aircraft industry.[28]

Exploration now gave way to rationalisation. In the rationalisation phase funding was removed from those projects judged less successful, which were terminated, and was concentrated on fewer projects reflecting more limited priorities. Agents responded both defensively and aggressively. Then the cycle was repeated because in the course of rationalisation the principal made mistakes, curtailing some good projects as well as bad ones. Therefore, rationalisation was often temporary because agents would eventually mount challenges to central priorities and organisational monopolies from below and exploration would begin again. However, steam propulsion was only explored through one such cycle.

3.2. The Financing Decision

On the demand side of the financing decision were the *funding principals*. The fundholder and the funding department were not necessarily the same. The *fundholder* was the legal owner of the R&D assets, usually an industrial ministry, but the Red Army also maintained its own R&D establishments. The *funding department* paid for R&D services. Some centralised orders were paid directly out of the USSR state budget. In addition, budgetary institutions such as the defence commissariat were entitled to enter into decentralised contracts with industrial institutes and design bureaux for R&D services. Finally, the fundholder could also commission in–house research from its own establishments.

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[26] Hanson and Pavitt (1987), 46.

[27] See also Harrison (2001).

[28] Rodionov, 2001, 1936 under 3 August. Evidently, this request failed.

Both fundholders and funding departments operated within a framework of strategic directives that were issued from time to time by high–level government committees: the Council for Labour and Defence or the executive subcommittee of the Council of People's Commissars responsible for defence matters. In practice, regardless of the formal issuing authority, Stalin personally made such decisions in secret consultation with a varying circle of individual Politburo members, usually after receiving representations from the funding department and fundholder.[29]

Within this framework both funding departments and fundholders formulated operational plans. The most important planning horizon was annual. The Red Army had an annual plan for the development of military inventions some of which it funded directly through its own R&D establishments and some of which it contracted out to other organisations. Industrial ministries, including the branches of the defence industry, had their own R&D plans. This included the aircraft industry's annual plan for aeroengine research and experimentation to be carried out by its own institutes and bureaux, part of which was made up by contracts accepted from the Red Army.

How did projects win a place in the plan? There was a variety of routes, but their common feature was that 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. Established designers continually brought proposals for radical innovations to the attention of funding principals; it was their job to do so. For example, here is deputy minister for the aircraft industry M.M. Kaganovich again in August 1936:[30]

> Three years ago comrade Tsvetkov came to me and proposed making such a turbine, I went to the boss, the people's commissar signed a decree to the effect that, in urgent order, under personal responsibility, [inaudible] to build a turbine […]

Successful proposals required investments in lobbying. Such investments could bring not only success for individual proposals but also long–term privileged relationships with government officials responsible for funding. To win support for their projects and adoption of their designs, designers had to be "heterogeneous

[29] Rees (2001).

[30] RGAE, 8328/1/824 (22 August 1936), 35.

engineers" capable of reshaping organisational as well as technological constraints.[31] To create a demand for new designs they had to build coalitions with soldiers or industrialists to overcome producer and consumer interests vested in markets for products that already existed.

Much has been written about Marshal M.N. Tukhachevskii, Red Army chief of armament from 1931 to 1936, as the military patron of jet propulsion in the Soviet Union between the wars.[32] Tukhachevskii was an assiduous networker; he used his oversight of military R&D to seek a monopoly of jet propulsion development for both artillery and aviation as both funding principal and fundholder. In this ambition he was never successful. But it is notable that the first projects in steam propulsion were also sponsored by establishments of the Red Army, one of them (KB–2) directly under Tukhachevskii's control as chief of armament at the time.

One way of weighing the question up is to ask what was the most important difficulty for the funding principals: was it to *promote*, or to *limit* the number of projects involving steam propulsion? The clear–cut answer to this question is that the funding principals struggled continually to limit and constrain initiatives and proposals from below. Rather than the funding principals having to stimulate activity at lower levels, it was initiatives from below that stimulated higher–level interest and found patrons. These initiatives were diverse and flowed from many sources, and were much more numerous than initiatives from above. As a result R&D projects had a tendency to proliferate that the funding principals found difficult to control. This is reflected in the character of high–level decisions: reports and resolutions prescribing the consolidation or cancellation of existing rival projects greatly outweighed the number of decisions authorising new ones.

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[31] On heterogeneous engineers see MacKenzie (1996), 13, and Harrison (2001) for further illustration.

[32] In November 1929 the post of chief of armament of the Red Army was created to help carry through its equipment modernisation. The first chief of armament was Army Commander I.P. Uborevich, followed in 1931 by Army Commander, later Marshal M.N. 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, 321). For reasons that are largely unrelated to this topic Tukhachevskii was arrested in May 1937 and, along with many other officers, subsequently executed as a traitor. On Tukhachevskii and jet propulsion see Holloway (1982b), Siddiqi (2000), and Harrison (2001). On Tukhachevskii and Red Army rearmament generally see Samuelson (1996 and 2000) and Stoecker (1998).

3.3. Refinancing

When projects are long term, projects in progress require periodic refinancing. Alternatively, they must be discontinued. By examining refinancing decisions affecting projects in progress we can learn more about the incentives facing designers and funding principals and the calculations they made.

Under the system that I have described, projects arose out of initiatives from below. The role of funding principals was reactive and planning decisions tended to validate these initiatives. Consequently projects in progress were normally refinanced without an explicit decision to this effect being reported. The fact that a project had been previously approved so that initial funds had been disbursed and work begun was a sufficient reason, other things being equal, for funding to be continued.

This raises the possibility that principals were indifferent to R&D failure. Could it be that they distributed project funding to agents in return for political rather than technological payoffs? If so, one could expect the principal to have responded to the agent's failure by emphasising shared objectives, the difficulties intrinsic to the task, the agent's praiseworthy efforts as a foundation for future progress, and the value to the agent of the principal's continued support, together perhaps with the value to society of the experience so far accumulated and other positive externalities. But the evidence does not match this at all. An unusual insight is provided by the ministerial review of continuing steam turbine projects held in August 1936. Kaganovich's mood was one of intense frustration, not indifference to failure; he interrupted the designers repeatedly with heavy sarcasm:[33]

> With existing dimensions is it sensible or feasible to place such a plant in an aircraft? One turbine engineer suggested placing 5 turbines in an aircraft, but for this the aircraft must weigh 125 tons without additional payload. You could put a F[eliks] D[zerzhinskii] locomotive in an aircraft, but then the aircraft would weigh 2000 tons. This is comrade B[inaudible]'s fantasy, he's got 245–metre wings and a 45–metre fuselage.
>
> […] We're not talking about a boiler on a Tsvetkov *locomotive.* Whoever's first to give us a turbine, we'll take it and work with it and the result will be that the airscrew will turn on the ground, if we put an airscrew on a locomotive it'll also turn, but we need to put it in *an aircraft at altitude* [emphasis added].

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[33] RGAE, 8328/1/824 (22 August 1936), 12, 15, 35, 51, and 52 respectively.

> […] Three years ago comrade Tsvetkov came to me and proposed making such a turbine, I went to the boss, the people's commissar signed a decree to the effect that, in urgent order, under personal responsibility, [inaudible] to make a turbine, [they] began to make it, and now he comes and says: "There's a turbine but no boiler". That's how they move technology forward. It's as if we got pig–iron but no metal.
>
> […] I said to comrade Aksiutin […] I'll give you a TB–7 airplane, smash it to pieces if you want, but taxi it along, lift it up to 100 metres, and then it will be a deed of proof that a turbine lifts up. Whatever it costs I'll pay. But […]
>
> […] I can't sit for three years and see no results.

The designers' response was to plead for time to allow the technology to evolve. They promised to build smaller, more efficient boilers and condensers. The aircraft designers Petliakov and Lavochkin were present. It was obvious that the engines being designed would not fit an existing airframe, so Petliakov asked that the turbine engineers should give more consideration to aircraft design and Kaganovich made him responsible for liaison.

Money and time had been spent, and while there was the smallest possibility of a positive outcome Kaganovich was not going to give up. The costs already sunk meant that the steam turbine projects drifted on for two or three more years. During 1937 a turbine of the Khar'kov Aviation Institute was prepared for installation in a TB–7, but the attempt was recognised to have failed by the end of the year.[34] One defensive response to the lack of progress was diversification: in January 1938 special–purpose design bureau (SKB) director Sinev referred his superiors to the value of potential spinoffs from his bureau's work on aviation steam turbines for other branches: naval and locomotive engineering.[35] Only one decision to terminate a project has been found: in July 1938 the Moscow Aviation Institute's design bureau was closed for failure to progress with the binary cycle turbine.[36] Other projects simply vanished one by one from plans and reports.

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[34] Rodionov (2001), 1937 under annual prologue and epilogue.

[35] Rodionov (2001), 1938 under 15 January.

[36] Rodionov (2001), 1938 under 21 July. In the aircraft industry several design bureaux were closed during the Stalin years as a punishment for failure to create successful designs: Albrecht (1989), 136 and 215, lists those of Kalinin,

4. Competitive Threats

4.1. Takeovers and Mergers

An R&D project can be thought of as a long–lived capital asset. All economies need mechanisms for restructuring these assets and transfering ownership through time.[37] In the case of R&D projects this mechanism is created by their need for periodic refinancing, which has the necessary effect of creating a secondary asset market. Under Soviet law state ownership rights over R&D project were delegated to ministerial fundholders by whom such rights were not transferable. In reality there were substantial incentives for agents to mount takeover or merger bids for projects of other fundholding departments.

One motive was profit: the predator could compare the value of a project in progress with the costs of taking it over. The value of a project lay in the sunk costs represented by its tangible and intangible assets. These costs had already been incurred at the expense of some other department to whom the new fundholder did not have to pay compensation. Takeovers were costly nevertheless. 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 ownership rights over economic assets on which all fundholders ultimately relied.

Another motive was competitive threat: it might be more dangerous to abstain from the secondary market than to enter it. For example, small establishments were continually at risk of being swallowed by larger ones. The command system favoured large projects because of their economies of scope: larger units required fewer lines of outside communication and were less reliant on outsiders for essential goods and services. The preference for scale was reflected in frequent calls to eliminate duplication of effort and "parallelism". Calls for rationalisation and centralisation were rarely if ever questioned; they were regarded as progressive almost beyond debate, especially when comparisons were made with the scale of R&D establishments in aeroengineering abroad.[38] Smaller units had to expand in order to hold off threats from larger rivals, and one method of expansion was through

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Shcherbakov, Berezniak and Bolkhovitinov, and Gudkov. In some cases the chief designer was imprisoned (Gudkov) or executed (Kalinin).

[37] Gregory and Lazarev (2000) provide a study of the Soviet economy's informal secondary market in another capital good, the motor car.

takeover. Consequently neither large nor small units benefited from restraint, and larger units too were continually on the lookout for opportunities to propose favourable rationalisations of the industry by absorbing smaller ones.

The logic of the takeover bid was a restructuring of liabilities. Consider a failing project, i.e. one that had incurred significant sunk costs without giving results on schedule. Was the project intrinsically bad, or just badly funded or led? If the lack of results compared with the sunk costs could be ascribed to poor resources or organisation, then it was efficient to write off the sunk costs and refinance the project under new management. Such a logic was strengthened when the scope of activity and the number of projects was on the increase because this also brought a rising number of potentially weak projects.

For example in December 1937 special–purpose design bureau (SKB) acting director Sinev submitted a memorandum listing six steam turbine projects in progress in four different institutes and three different cities. Welcoming the piecemeal advances already made, he criticised their “cottage–industry” scope (*kustarshchina*). Claiming the support of his own team and the Khar’kov project leaders, he called for all the groups to be brought together in a single “unified production–experimentation base” in Moscow, with close links to the aircraft industry.[39]

Another channel for proposals for concentration at this time was the system of peer review. Thus late in 1937 the gas turbine designer V.V. Uvarov of the All–Union Thermal–Technical Institute (VTI) was commissioned to report to the commissariat of the defence industry on the progress of the “gas–steam turbine” being developed at factory no. 18 by designers Dybskii and Udod. After commenting on the weaknesses that he had observed, Uvarov commented:[40]

> the continuation of work on the lines under investigation should be curtailed, the more so since work on steam and gas turbocompressors is already going on [elsewhere]. *These two lines [of work] completely cover the authors’ design, and for this reason duplication will yield nothing new.*

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[38] RGAE, 8044/1/460, 49–51 (31 December 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] RGAE, 8328/1/992, 14–18 (19 December 1937).

[40] RGAE, 8328/1/996, 22–24 (1 January 1938): emphasis added.

4.2. Defensive Measures

One way in which R&D agents defended projects in progress against competitive threats was by creating and reinforcing monopolies in new explicit knowledge. Implicitly, designers did not trust or sufficiently value existing rights of authorship under Soviet law. They sought to prevent rivals from grabbing new knowledge to underpin competing proposals for development funding. Such rival projects would have looked "good" because they would not have had to account for costs of experimentation already sunk.

For example, at the August 1936 ministerial review of steam turbine projects it became apparent to Kaganovich that some barriers against the collaboration among designers that he desired were created by the designers themselves, supported by their departmental superiors. Development work for the Aksiutin turbine was proceeding at the Leningrad Kirov factory (LKZ), but without results. Why had engineer Vinblad failed to make himself useful to Aksiutin on the LKZ site? Because no one would issue him with a pass. Why not? A participating engineer commented: "[..] because there was rivalry, the special proprietary interest [*opeka*] of each in this business. Each was trying to turn this business into one [associated with] his own name".[41] In response, Kaganovich was simultaneously reassuring and threatening:[42]

> I will take all measures to protect the authorship of one or another comrade at work. If it's Aksiutin's turbine so let it be, but if he's up to some fabrication, and not up to realising a technical solution to the problem, and for this reason has kept Vinblad away from the installation for a full year, then that is an obvious criminal act and an obvious detriment to the value of the turbine for our work.
>
> In our country there are no secrets and the designer who holds on to big secrets and does not carry them out into life — in the capitalist world he would simply perish and in the socialist [world] he is simply good for nothing. That's why we will set in train all measures and powers to help you realise the ideas and creativity that you have performed, while you are guaranteed full protection of authorship.

Designers also defended themselves against hostile takeovers by lobbying. For example in 1938 a new struggle arose for control over the development of aviation steam turbines: yes, this was still "work in progress", and the lack of results was

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[41] RGAE, 8328/1/824 (22 August 1936), 38.

[42] RGAE, 8328/1/824 (22 August 1936), 35, 52.

being attributed not to intrinsic badness of the project but to dispersion of resources and duplication of effort. In June the commissariat of the defence industry submitted to Molotov its long–delayed draft plan for aeroengine experimentation for that year. It proposed that all work on aviation steam turbines should be concentrated in the Central Boiler and Turbine Institute (TsKTI) in Leningrad and that a grant of 2.5 million rubles should be made to TsKTI to expand its plant and equipment for this purpose.[43] On the defensive this time, SKB director Sinev wrote to Molotov, the Kaganovich brothers (one the commissar for the defence industry, the other the responsible central committee secretary), and defence commissar Voroshilov to protest this recommendation.[44] Sinev made three charges against TsKTI: it lacked an "aviation culture"; it was ineffective even at its primary task, the design of steam turbines for power stations; and it was already "over–encumbered" (*gromozdkaia*). Again he proposed the formation of a new bureau in Moscow based on one from a range of existing aviation establishments.

On this occasion the defence failed; it was referred to air force chief Loktionov, who rejected it and upheld the recommendation in favour of TsKTI.[45] And as table 1 shows 1938 saw the end of aviation steam turbines at SKB. On the other hand the victory of TsKTI was hollow, because steam aviation was going nowhere and all such projects had been closed down by the end of 1939. In the end, after spending tens of millions of rubles, everyone had to recognise that these were just *bad projects*.[46]

5. Good and Bad Projects

The problem of the principal was how to select and monitor long lived projects of uncertain worth. In the presence of sunk costs there was a tendency for both the funding principal and the R&D agent to be motivated to continue projects that the principal would have preferred not to finance in the first place. The result was that selection could become adverse: R&D agents were motivated 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. Moreover, if results fell short when refinancing

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[43] RGVA, 4/14/1925, 232–248 (26 June 1938).

[44] RGVA, 4/14/1925, 150–152 (17 May 1938).

[45] RGVA, 4/14/1925, 155 (19 May 1938).

[46] And Sinev was arguing for 10 million rubles *more*. RGAE, 8328/1/992, 15 (19 December 1937).

became necessary, the designer could always shift blame to the funder since the first instalment of funding was always less than the amount originally proposed.

What factors determined whether a project was "good" or "bad" from the point of view of the national mission? This depended on four factors: the as–yet–unknown state of nature, the level of funding, the organisation of resources and teamwork, and the motivation of the design team. First, the state of nature determined whether or not the project was intrinsically bad. Second, even for an intrinsically good project the level of funding needed to be appropriate to the task. Third, the physical and human resources employed on the project required effective organisation, including teamwork and leadership; a design team that lacked the right equipment or was poorly led would give poor results. Finally, success depended on motivation: what was good or bad depended on whether the state saw it the same way as the designer. Thus some inventors involved in jet propulsion R&D may have been motivated otherwise: to realise a dream, to build an empire, to live in style, or to live in peace. In 1937–8, official suspicions of "other" motivation were sometimes hardened into the designation "enemy of the people". It is not necessary to go to this extreme to accept that R&D agents' motivations were not necessarily aligned at all times with the preferences of the state.

When a project failed, did it matter whether it was intrinsically bad, or potentially good but poorly funded or organised? With funding rationed and entry controlled, the danger was that bad projects might drive out good ones. Therefore the funding authorities made great efforts to diagnose the causes of project failure to see if they could be rectified. However, it was also extremely difficult, and perhaps impossible, to do so without hindsight. Even with hindsight it is still very difficult, and for this reason I avoid comment on the intrinsic goodness or causes of failure of individual projects. Only classes of project can be evaluated in this way; for example, all the aviation steam turbine projects were intrinsically bad, but I do not know which ones were also poorly funded or poorly led.

The various research establishments reported regularly to higher authority on each project in progress. From time to time the same authorities launched special reviews which ranged from round–table exchanges of specialist opinion concerning common difficulties shared by several projects, and specific investigations of specific projects thought to be at risk of failing.

The difficulty of establishing the causes of project failure made it easy for designers to displace the blame for their own lack of success. As has already been shown, designers sometimes faulted the funder for dispersing funding too widely, that is, sharing it with rival projects: they argued that more time and more focused funding would turn their own project round. Designers also blamed producers for failure to share the motivation of the design, leading to incompetent or neglectful preparation of components and assemblies. For example, the steam turbine designer Aksiutin complained to Tukhachevskii in 1935 that the Leningrad Kirov factory (LKZ) was incapable of playing a constructive role because it was gripped by "a certain conservatism utterly alien to the aviation culture" and commented that LKZ had declined a contract to build an Uvarov turbine for VTI giving as its official reason that the turbine required "too many parts to be completed to 'aviation standards' that would be an embarrassment for the factory [*chto dlia zavoda zatrudnitel'no*]".

According to the recollection of the aircraft designer A.S. Iakovlev, Stalin himself reflected on the tendency of designers to displace the blame for their own lack of results:

> A designer is a creative worker. Like the painter of a picture or the writer of a literary work, the product of a designer's or scholar's creativity can be successful or unsuccessful. The only difference is that from a picture or verse you can tell the author's talent right away. […] With a designer it's more complicated: his design can look very attractive on paper, but final success or failure is determined much later as a result of the work of a numerous collective and after the expenditure of substantial material means … Most designers get carried away with themselves and are convinced of their own and no one else's righteousness; on the basis of an overdeveloped self–regard and the mistrust that is characteristic of every author they tend to attribute their own failures to prejudice against themselves and their creations.[47]

Were the different intrinsic motivations of R&D agents a factor in project success and failure? Stalin understood that Soviet funding institutions offered a degree of protection for self–serving interests; this created a rationale for him, with his security chiefs N.I. Ezhov, then L.P. Beriia, periodically to mount cruel inquisitions into the souls of the scientists and engineers.

It is not clear whether the steam turbine engineers escaped the general bloodletting in 1937–8.[48] The MAI experimental design bureau was closed down but the fate of its steam turbine designer Przheslavskii is not known. SKB director Sinev went on to become deputy chief designer at the Leningrad Kirov factory (LKZ) in

[47] Iakovlev (2000), 501.

[48] The relationship between success, failure, and punishment in the Great Terror was complex. See Manning (1993).

wartime, subsequently director of the LKZ experimental design bureau, and a leader of the postwar uranium industry.[49] And Aksiutin reappeared in Voronezh in 1947–8 as chief designer of an experimental aeroengine design bureau in factory no. 154.[50]

Finally, if the steam turbine projects were bad projects, what further light has been thrown on the possibility that principals deliberately tolerated or fostered them in order to distribute rents? Evidence that the funding of steam turbine projects was continued despite evidence of failure in order to promote vertical relationships of trust and loyalty has not been found. Their continued refinancing is sufficiently explained by sunk costs and the difficulty of diagnosing the causes of project failure. By western standards the Soviet termination of steam turbine projects in 1939 was timely. For example two or three years after this, when the jet engine was already proven in flight, expert opinion in the west had still not finally written off the prospects of steam power for aviation.[51] Evidence from other fields of Soviet military R&D also confirms that, when rent–seeking was identified, it was punished.[52]

6. Conclusions

During the 1930s the Soviet Union probably invested more resources in steam power R&D than in jet propulsion or rocketry, and possibly as much as all other countries put together. An investigation of the results suggests a number of findings of more general significance.

1. In the Soviet Union steam power R&D was carried out in the context of a vertically organised command system. Within this context there was a great deal of market–like activity on the supply side including horizontal rivalry and competitive rent–seeking, a secondary market in R&D projects involving takeover and merger activity, and attempts to create and defend monopolies.

2. In the Soviet command system the designer took the initiative. There was no shortage of inventiveness and there were more proposals for radical innovations than the authorities were willing to fund. The main problem for the authorities was to control, not to promote inventive activity.

3. In the Soviet economy the scale of steam power R&D was that of an artisan industry. The resources available for such research were extremely limited and

[49] Lebina (2000), 188.

[50] RGAE, 8044/1/1637, 112 (12 June 1947) and 8044/1/1795, 109 (May 1948).

[51] Smith (no date), 36.

[52] Harrison (2001).

funding was rationed. However, budget constraints on individual projects in progress tended to become soft. 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.

4. Designers who were successful in getting their proposals selected for 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 rationalisation.

5. It was difficult or impossible for the authorities to tell good ideas from bad ones. The difficulty beforehand reflected technological uncertainty and agents' unobserved characteristics. It was not much less difficult when projects were in progress because projects could fail for reasons unrelated to the goodness of the original idea. In the presence of sunk costs, refinancing a project in progress was usually easier than terminating it. It is possible that adverse selection resulted.

6. There is no evidence that rents were intentionally distributed through the Soviet military R&D system to win trust or reward loyalty; the termination of aviation steam power R&D in 1939 despite the sunk costs they represented was timely.

Table 1. Major Soviet R&D Projects for Aviation Steam Turbines, by Establishment, 1932 to 1939

	1932	1933	1934	1935	1936	1937	1938	1939
1. KhAI	Tsvetkov 15 000hp turbine———| Tsvetkov “air–naval” PT–6 (6000hp)———|				PT–6 (3000hp) ———|			
2. NII GVF	PT–3 (3000hp) “air–naval” steam turbine———|							
3. VVA	Aksiutin PT–1 (1500/2500hp) turbine (continued at SKB and Energeticheskii institut)							
4. SKB	Sinev turbine					Sinev 1600/2500hp turbine———|		
5. E.Inst						Aksiutin turbine (from VVA) ———|		
6. KB–2		Kozhevnikov 400hp gas–steam turbine———|					
7. VTI				“Air–naval” 1000hp turbine		Przheslavskii 2000hp binary–cycle steam turbine———		
8. MAI							———|	
9. TsKTI						Hüttner turbine	VT–1, VTK–100 (100hp), and VTK–3000 (3000hp) turbines	PT–1M (2000hp) and VTK–300 (100hp) turbines
10. Zavod no. 18						Dybskii–Udod gas–steam turbine———|		
11. TsIAM								1600hp, single–, and binary–cycle turbines

Sources and Key to Design Establishments: see next page.

Sources for Table 1

RGAE, 8044/1/994, 21–23; 8328/1/696, 25; 8328/1/824, 1–50; 8328/1/919, 84; 8328/1/992, 6–7; 8328/1/996, 16–18, 22–23ob. RGVA, 4/14/2800, 4; 34272/1/167, 23–24, 47–55, and 102–119. Rodionov (2001), 1932 under the month of September, 17 Sept., and 31 Dec.; 1933 under 10 Feb. and 8, 21, and 23 March; 1934 under 3 and 14 July. The supporting documentation comprises plans, reports, and memoranda of the People's Commissariats of Defence, Heavy Industry, the Defence Industry, and the Aircraft Industry.

Key to Design Establishments

1. **KhAI** (Khar'kovskii Aviatsionnyi institut NKTP–NKOP–NKAP): Kharkov Aviation Institute of the People's Commissiat of Heavy Industry (later Defence Industry, later Aircraft Industry)

2. **NII GVF** (Nauchno–Issledovatel'skii institut Grazhdansko–Vozdushnogo Flota GUGVF SNK): Research Institute of the Civil Air Fleet of the Chief Administration of the Civil Air Fleet of the Council of People's Commissars

3. **VVA** (Voenno–Vozdushnaia Akademiia RKKA): Air Force Academy of the Workers' and Peasants' Red Army

4. **SKB**, later **SKB–1** (Spetsial'noe Konstruktorskoe biuro Pervogo Glavnogo upravleniia NKOP): Special–purpose Design Bureau of the First Chief Administration of the People's Commissariat of the Defence Industry

5. **E.Inst** (Energeticheskii institut AN SSSR): Energy Institute of the USSR Academy of Sciences

6. **KB–2** (Konstruktorskoe biuro no. 2 UVI RKKA): design bureau no. 2 of the Administration of Military Inventions of the Workers' and Peasants' Red Army (Leningrad)

7. **VTI** (Vsesoiuznyi Teplotekhnicheskii institut im. Dzerzhinskogo NKTP): Dzerzhinskii All–Union Thermal–Technical Institute of the Electricity Supply Industry Administration of the People's Commissariat of Heavy Industry

8. **MAI** (Moskovskii Aviatsionnyi institut NKTP–NKOP–NKAP): Moscow Aviation Institute of the People's Commissiat of Heavy Industry (later Defence Industry, later Aircraft Industry)

9. **TsKTI** (Tsentral'nyi Kotlo–turbinnyi institut Energoproma NKTP): Central Boiler and Turbine Institute of the Electricity Supply Industry Administration of the People's Commissariat of Heavy Industry (Leningrad)

10. **Zavod no. 18** (zavod no. 18 NKOP): factory no. 18 of the People's Commissariat of the Defence (later Aircraft) Industry

11. **TsIAM** (Tsentral'nyi Institut Aviationnogo Motorostroeniia NKTP–NKOP–NKAP): Central Institute for Aeroengine Building of the People's Commissariat of Heavy Industry (later the Defence Industry, later the Aircraft Industry)

Table 2. The Number of Major Soviet Projects for Aeroengines Based on Jet Propulsion and Turbines, 1 January 1932 to 30 June 1941

	1932	1933	1934	1935	1936	1937	1938	1939	1940	1941(1)
Steam turbines										
1. In progress at start of year	0	3	4	4	3	2	6	1	0	0
2. Starting during year	4	1	0	1	0	4	0	1	0	0
3. Continuing during year	4	4	4	5	3	6	6	2	0	0
4. Discontinued by end of year	–1	0	0	–2	–1	0	–5	–2	0	0
5. In progress at end of year	3	4	4	3	2	6	1	0	0	0
Gas turbines, jets, and rockets										
1. In progress at start of year	0	1	1	1	1	3	3	3	6	4
2. Starting during year	2	0	1	0	2	1	1	5	0	3
3. Continuing during year	2	1	2	1	3	4	4	8	6	7
4. Discontinued by end of year	–1	0	–1	0	0	–1	–1	–2	–2	0
5. In progress at end of year	1	1	1	1	3	3	3	6	4	7

Source: this table is adapted from Harrison (2001), table 2. For steam turbines specifically see table 1 of this paper. I count as one “major project” work that is continued in one establishment from year to year even though the particular objects may vary, and work that is continued on a particular object from year to year by one designer even though the sponsoring establishment may vary. Row [1] = [5] in the previous year; [5] = [4] + [3]; [3] = [2] + [1].

Table 3. Soviet Designs for Aviation Steam Turbines: Technical Characteristics.

Design establish–ment	Designer	Model	Capacity, horse–power	Weight, kilo–grammes	Specific weight, kilo–grammes per horse–power	Specific fuel consump–tion, grammes per horse–power per hour
KhAI	Tsvetkov		15 000	16 500	..	..
KhAI	Tsvetkov	PT–6	6 000 reduced to 3 000	9 600 reduced to 3 000	..	..
NII GVF	..	PT–3	3 000	3 000	..	..
TsKTI	..	PT–1M	2 000	..	1.0	300
SKB	Sinev	..	1 600 increased to 2 500	..	2.5	350–400
VVA–SKB–E.Inst	Aksiutin	PT–1	1 500 increased to 2 500	..	1.0	220
VTI	..	"Air–naval"	1 000	1 000	..	..
KB–2	Kozhev–nikov	..	400	..	0.65[a]	..

Sources: as table 1.

Note

[a] Excluding the weight of a gas turbocharger.

References

Official Papers

RGAE (Rossiiskii Gosudarstvennyi Arkhiv Ekonomiki), Moscow
RGVA (Rossiiskii Gosudarstvennyi Voennyi Arkhiv), Moscow

Publications

Albrecht, Ulrich (1993), *The Soviet Armaments Industry*, Chur (Switzerland): Harwood Academic Publishers

Arrow, Kenneth J. (1962), "The Economic Implications of Learning by Doing", *Review of Economic Studies*, 29(3), 155–73

Beath, John, Yannis Katsoulacos, and David Ulph (1995), "Game–Theoretic Approaches to the Modelling of Technological Change", in Paul R. Stoneman, ed., *Handbook of the Economics of Innovation and Technological Change*, Oxford: Blackwell, 132–81

Berliner, Joseph S. (1976), *The Innovation Decision in Soviet Industry*, Cambridge, MA: MIT Press

Dasgupta, Partha, and Joseph E. Stiglitz (1980), "Industrial Structure and the Nature of Innovative Activity", *Economic Journal*, 90, 268–93

Dewatripont, Mathias, and Eric Maskin (1995), "Credit and Efficiency in Centralized and Decentralized Economies", *Review of Economic Studies*, 62(4), 541–55

Gregory, Paul R., and Valery Lazarev (2000), "Stalin's Car Dealership: Evidence From the Soviet State and Party Archives", University of Houston, Department of Economics, available at www.soviet-archives-research.co.uk/

Grigor'ev, N.V. (1994), "Aviatsionnoe motorostroenie v Velikoi Otechestvennoi voiny 1941–1945 gg.", in G.S. Biushgens, ed., *Samoletostroenie v SSSR. 1917–1945*, vol. 2, Moscow: TsAGI, 164–96

Gunston, Bill (1995), *The Osprey Encyclopedia of Russian Aircraft, 1875–1995*, London: Osprey Aerospace

Hanson, Philip, and Keith Pavitt (1987), *The Comparative Economics of Research, Development and Innovation in East and West: a Survey*, Chur (Switzerland): Harwood Academic Publishers

Harris, James R. (1999), *The Great Urals: Regionalism and the Evolution of the Soviet System*, Ithaca, NY, and London: Cornell University Press

Harrison, Mark (2000), "New Postwar Branches (1): Rocketry", in John Barber and Mark Harrison, eds, *The Soviet Defence–Industry Complex from Stalin to Khrushchev*, Basingstoke: Macmillan, 118–49

Harrison, Mark (2001), "The Soviet Market for Inventions: The Case of Jet Propulsion, 1932 to 1944", The Warwick Economic Research Papers, no. 605, University of Warwick, Department of Economics

Holloway, David (1982a), "Innovation in the Defence Sector', in Ronald Amann and Julian Cooper, eds, *Industrial Innovation in the Soviet Union*, New Haven, CT: Yale University Press, 276–367

Holloway, David (1982b), "Innovation in the Defence Sector: Battle Tanks and ICBMs", in Ronald Amann and Julian Cooper, eds, *Industrial Innovation in the Soviet Union*, New Haven, CT: Yale University Press, 368–414

Iakovlev, A.S. (2000), *Tsel' zhizni. Zapiski aviakonstruktora*, Moscow: Respublika, 6th edn

Jasny, Naum (1952), *Soviet Prices of Producers' Goods*. Stanford, CA: Stanford University, Food Research Institute

Lazarev, Valery, and Paul R. Gregory (2000), "Dictators and Cars: a Case Study in the Political Economy of Dictatorship", University of Houston, Department of Economics, available at www.soviet-archives-research.co.uk/

Lebina, Nataliia (2000), “The Defence–Industry Complex in Leningrad (2): the Postwar Uranium Industry”, in John Barber and Mark Harrison, eds, *The Soviet Defence–Industry Complex from Stalin to Khrushchev*, Basingstoke: Macmillan, 184–94

Liul’ka, A.M., and S.P. Kuvshinnikov (1981), “K istorii sozdaniia pervogo sovetskogo turboreaktivnogo dvigatelia”, *Voprosy istorii estestvoznania i tekhniki*, no. 2, 86–96

MacKenzie, Donald (1996), *Knowing Machines*, Cambridge MA: MIT Press

Manning, Roberta T. (1993), “The Soviet Economic Crisis of 1936–1940 and the Great Purges”, in J. Arch Getty and Roberta T. Manning, eds, *Stalinist Terror: New Perspectives*, Cambridge: Cambridge University Press, 116–41

Mokyr, Joel (1990), *The Lever of Riches: Technological Creativity and Economic Progress*, Oxford: Oxford University Press

Ordway, Frederick I., and Mitchell R. Sharpe (1979), *The Rocket Team*, London: Heinemann

Rees, E.A. (2001), “Leaders and Their Institutions”, in Paul R. Gregory, ed., *Behind the Façade of Stalin’s Command Economy: Evidence from the Soviet State and Party Archives*, Stanford, CA: Hoover, 35–60

Rodionov, Ivan (2001), *The Aviation and the Aircraft Industry of the Soviet Union, 1916 to 1946*, 3rd edn, University of Warwick, Department of Economics, available at www.warwick.ac.uk/economics/harrison/aviaprom/

Samuelson, Lennart (1996), *Soviet Defence Industry Planning: Tukhachevskii and Military–Industrial Mobilisation*, Stockholm: Stockholm School of Economics

Samuelson, Lennart (2000), *Plans for Stalin's War Machine: Tukhachevskii and Military–Economic Planning, 1925–1941*, London and Basingstoke: Macmillan

Siddiqi, Asif A. (2000), *Challenge to Apollo: The Soviet Union and the Space Race, 1945–1974*, Washington, DC: NASA History Division (NASA SP–2000–4408)

Smith, G. Geoffrey (no date), *Gas Turbines and Jet Propulsion for Aircraft*, London: Flight Publishing Co.

Stodola, Aurel (1927), *Steam and Gas Turbines*, New York: McGraw–Hill

Stoecker, Sally W. (1998), *Forging Stalin’s Army: Marshal Tukhachevsky and the Politics of Military Innovation*, Boulder, CO: Westview

Voronkov, Iu.S. (1984), “Teoriia i konstruktsiia: istoriia vzaimodeistviia pri sozdanii pervykh aviatsionnykh reaktivnykh dvigatelei”, *Issledovaniia po istorii i teorii razvitiia aviatsionnoi i raketo–kosmicheskoi nauki i tekhniki*, vyp. 3, Moscow: Nauka, 113–22

Wintrobe, Ronald (1998), *The Political Economy of Dictatorship*, Cambridge: Cambridge University Press