Cost–Benefit Analysis of Investment in High-Speed Train System in Spain

Gema Carrera-Gómez, Juan Castanedo-Galán, Pablo Coto-Millán, Vicente Inglada, and Miguel Angel Pesquera

This study compares the results of two political approaches to transport directed at the reduction of negative external effects. The comparison is between a policy of building a high-speed rail line to attract travelers away from highways and full social-cost pricing on all modes, that is, removing the implicit subsidies to all modes by pricing congestion and external costs. The former approach was adopted in 1992 in Spain with the introduction of the high-speed train in the Madrid–Seville corridor, bringing with it an important increase in the modal share of railway transport. From the analysis made, it can be concluded that from the point of view of economic efficiency and social benefit optimization, the high-speed train should not have been implemented that year (1992) in the Madrid–Seville corridor. Other transport policy approaches, such as the introduction of an optimal modal price based on the respective marginal social costs, would have increased social benefit. Therefore, the results obtained in this investigation indicate the necessity to introduce higher economic efficiency in the transport market through the application to each mode of transport of a price based on the marginal social cost.

Along with the economic benefits that business sectors and consumers reap as a direct consequence of time reduction in journeys, there is also a broad set of negative effects (noise, particles, vibration, accidents, emissions, natural resource destruction, congestion, and visual intrusion), which constitute a high cost in loss of social benefit. Most of these external effects do not carry a price due to their own nature—in other words, there is not a clear market system that provides users with sufficient evidence and is able to charge the social costs to the polluter. Therefore, there is a distortion in the market functioning, and the social costs do not coincide with the private costs. Because the mechanism of prices does not act, there is an overuse of the service above the corresponding social equilibrium of the transport market. To summarize, there are shortcomings of barriers to the efficient development of markets, and the current price is below the optimum.

The Plan of Infrastructure and Transport of the Spanish government contemplates that the volume of investments in railway infrastructure will surprisingly exceed that directed to roads. An ambitious action plan consists of having more than 10,000 km of high-speed train network for 2020. If such an objective were fulfilled, Spain would occupy the leading position in total length of high-performance railway network.

This paper includes five sections and conclusions. The second section analyzes the main guidelines observed in the development of Spanish passenger and goods transport demand, as well as the corresponding modal distribution. The third section studies transport externalities focusing on the analysis of the optimal price’s theoretical framework, the internalization instruments, and the valuation in money terms of the considered external effects (congestion, environment, maintenance, and accidents). The fourth and fifth sections compare the effects on social benefit and modal distribution of the two transport policy approaches in the Madrid–Seville corridor: (a) levying of a charge on the price in all modes of transport that internalizes the social costs of each transport mode and (b) introduction of the Alta Velocidad Española (AVE) high-speed train. Finally, the sixth section presents conclusions derived from the obtained results.

DEVELOPMENT OF TRANSPORT DEMAND

The first significant feature inferred from the development of Spanish passenger and goods transport demand is its dramatic growth during the past 50 years. This evolution has been parallel to that of economic activity, though with a higher rhythm, in both the up and down periods of the business cycle.

However, guidelines cannot be generalized in this growing trend of the demand for transport modes, because the increase in the volume of railway traffic has been slightly lower than that of its competitors, especially roads. In fact, only during the few periods of weak economic activity has railway traffic grown above the remaining transport means. This process has led to a quick decrease in railway modal share, both for passenger transport and—in an even higher volume—for goods transport (7).

Finally, the process observed in the Spanish case is in general applicable to other countries, although the loss of modal share of railway transport is much less marked than in Spain (2).

Among the factors that have been implied in the increased mobility by private car are the significant improvements—especially in qualitative terms—of the road network in Spain. The Spanish railway infrastructure has remained almost unchanged, however, with the exception of the new Madrid–Seville high-speed train, which is used only for passenger transport. With regard to the financial resources absorbed by each transport mode, the ratio between investment in roads and railway infrastructure—lower than 2 during the first years of the 1980s—has increased to reach a value greater than 5 in the 1990s. Other factors are a general rise in income and a rise in leisure time (2).
As far as goods transport is concerned, the transcendental changes undergone by the productive process as well as the supply chain have encouraged the role of freight transport because of its higher reliability and flexibility to adapt to changes in demand. In summary, the main factors in the increase in freight transport are the rise in flexibility in delivery; the trend toward high-value, low-volume goods; the need for just-in-time transport; and containerization.

TRANSPORT EXTERNALITIES

Concept

Only externalities discussed by Rothengatter (3, 4) are studied. These are, to summarize, activities outside the market but sufficiently relevant to alter their efficient functioning, therefore forcing state involvement to reduce their impact. In this sense, only technological externalities will be included, as the effects of so-called pecuniary externalities on other markets are transferred through the mechanism of relative prices and thus, with aggregation on all of them, the final effect is nil.

To study transport externalities, a classification in four clearly differentiated groups constitutes a useful starting point: damage to the infrastructure due to the use and wear of pavement, congestion costs, accident costs, and costs closely related to environmental damage and noise.

Internalization

For the internalization of the external effects of transport, there are four major types of instruments: economic incentives, regulatory instruments, actions on infrastructure and transport service supply, and information and persuasion measures (5). Economic instruments based on action on the prices are adequate from the point of view of economic efficiency because they create a constant financial incentive to reduce externalities (5). Toll is the instrument chosen in this study for the internalization of the external effects on roads. For other transport modes, the charge is included in the corresponding fares.

Theoretical Framework

The theoretical framework used is that used by Jansson (6). The objective is to maximize the sum of consumer and producer surpluses, once the costs of the negative externalities borne by the rest of society have been subtracted.

Thus, the net social benefit must be maximized as follows:

\[ \text{NSB} = \int_0^Q U(Q)dQ - Q \cdot AC^{ext} - TC^{prod} - TC^{ext} \]  

(1)

where

\[ \text{NSB} = \text{net social benefit}, \]
\[ U(Q) = \text{marginal utility (MU) function}, \]
\[ AC^{ext} = \text{average costs of users}, \]
\[ TC^{prod} = \text{total cost for the producer of transport infrastructure services}, \]
\[ TC^{ext} = \text{total external cost}, \]
\[ Q = \text{traffic volume}. \]

An equilibrium condition that must be satisfied is that the generalized cost (GC), equivalent to the sum of price \( P \) and the average user cost \( AC^{user} \), may be equal to the marginal utility:

\[ P + AC^{user} = U(Q) \]  

(2)

Finally, if the first-order condition is imposed to a maximum, which requires that the derivative of the net social benefit with respect to quantity \( Q \) equals zero, the following price is obtained:

\[ P = MC^{prod} + Q \frac{dAC^{user}}{dQ} + MC^{ext} \]  

(3)

where \( MC^{prod} \) is the short-run marginal cost of the producer of transport infrastructure services and \( MC^{ext} \) is marginal external cost.

Therefore, a known result has been achieved; it implies that a necessary condition to maximize net social benefit is that the price is set equal to the sum of the short-run marginal cost of the producer of transport infrastructure services, the cost imposed on fellow users, and the cost imposed on the rest of society by an additional user of transport infrastructure facility concerned. Externalities are internalized only when those who cause the costs also pay the total cost. In this sense, with the objective of facilitating this price setting, maintenance, environmental, congestion, and accident externalities will be analyzed separately for this study (7).

External effects create a divergence between private and social costs. The economic effects are illustrated in Figure 1. In Figure 1

![FIGURE 1](image-url)
the market equilibrium quantity $Q^e$ represents the amount that is actually produced and consumed, corresponding to the intersection of the supply and demand curves (balancing of marginal private costs and benefits). If there are external costs, the marginal social cost (MSC) curve lies above the market supply curve [marginal private cost (MPC) curve]. The socially efficient solution would be found at the intersection between the MSC curve and the demand curve (D). To achieve the socially optimal location $(Q^{mp}, G)$, a toll (or tax) of amount HB can be introduced to the user. In addition, according to Walters (8) and Hau (9), it can be observed that the area of the triangle HLE is the gain of social benefit obtained when adopting a generalized price value for transport, equivalent to the marginal social cost.

**Valuation**

The need to valuate monetarily the external effects has brought about new valuation techniques, which have been applied with special emphasis in the case of environmental goods. In this study, specific methodologies for each type of external effect were used, thus avoiding the mere transfer of values obtained in studies made in other regions or in Europe. In particular, this study is intended to reflect the specific characteristics of Spain, exclusively in relation with interurban transport.

**Congestion**

This externality has been studied specifically for road transport. The study is based on the work of Coto and Inglada (10), applying it to the Madrid–Seville corridor. Given that the cost of congestion does not vary linearly with the level of traffic, the Madrid–Seville corridor has been divided into eight links, according to the homogenous traffic volume criterion on each link. This characteristic—that the cost of congestion does not depend linearly on the traffic volume—leads to developing the marginal social cost of congestion after evaluation of the remaining external effects and to using a value of price elasticity of demand (Table 1) that shows the sensitivity of the demand to transport price, once the cost of congestion has been introduced.

In line with this, it is necessary to estimate the travel time value, which makes it possible to convert time into monetary cost for the user. The values mentioned in Manual de Evaluación de Inversiones en Ferrocarril de Vía Ancha (11) have been used.

**Maintenance**

Infrastructure damage costs are costs that arise because vehicle passage damages the track (i.e., road) surface. Once the hypothesis that the increase in vehicle operating costs caused by the deterioration of the road is not considered because of its low magnitude, the social cost associated with the wear and tear of transport infrastructures would be only the public investments that are not transferred to the user by fixing a price. The methodology used is based on Muñoz-Alamillos (12). Expenditures on infrastructure are distributed among the types of vehicles according to the different allocation criteria. Common criteria in the railway and road transport modes are used.

**Accidents**

This transport externality—from the economic and especially from the social point of view—arouses great interest and concern in our society. The marginal accident cost is the economic value of the change in accident risk when a user enters the traffic flow (this risk relates to this user as well other users). Marginal external accident cost is understood as the difference between the marginal accident cost and the private marginal cost (a part of the marginal accident cost that is internalized by the user).

The process used to obtain the social cost of accidents for each mode of transport is based on Inglada (13). First, total hospital and administrative costs are determined with a view to working out the noninternalized portion because in Spain the medical costs are covered by the social security system and consequently paid for with public funds. Second, the cost component called "net production losses" has been obtained. Then, the immaterial component of the social cost of accidents is valued by subtraction from the value that citizens are willing to pay for the loss of a human life and for an injured person, the already internalized part through the corresponding legal indemnities. To determine these unit values from the methodology based on users' willingness to pay, the value of statistical life for fatalities provided by the European Commission (14) has been considered and adapted to the Spanish case. Finally, the total of the social costs relative to road accidents has been distributed among the users—car, bus, and truck—according to the responsibility of the user, derived from accident statistics based on police reports (15, 16).

**Environment**

This externality includes noise, local pollution, and global warming. For noise, the INFRAS/IWW methodology (15, 16) was used. The valuation of external effects associated with pollution is based on the CORINAIR inventory—specifically made for Spain by the European Environmental Agency. The values provided by INFRAS and IWW (15, 16) have been used for air transport. In passenger and goods railway transport, there are two types of traction power—electric and diesel—so different methodologies must be used to determine their emission factors. For electric traction, the original sources of electric energy production should be analyzed. The emissions per passenger kilometer in the electric traction railway (intercity, AVE, and goods) have been determined from the distribution for each type of primary energy of the electric power production by the application of the energetic consumption to the corresponding occupation rates. In line with this, diesel traction railway and the remaining modes of transport have been operated by applying the amounts of units emitted to energetic consumption.

Once the factors of the units emitted for each mode of transport, for both passengers and goods, have been determined, it is necessary

<table>
<thead>
<tr>
<th>TABLE 1</th>
<th>Price Elasticities Considered in Passenger Transport</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Estimated Values</td>
</tr>
<tr>
<td>Car (petrol)</td>
<td>Coach (diesel oil)</td>
</tr>
<tr>
<td>Car (petrol)</td>
<td>-0.25</td>
</tr>
<tr>
<td>Coach (diesel)</td>
<td>-0.16</td>
</tr>
<tr>
<td>Train</td>
<td>0.42</td>
</tr>
<tr>
<td>Plane</td>
<td></td>
</tr>
</tbody>
</table>

SOURCE: (17) and authors' work.
to have unit costs available. These values have been obtained from Nijkamp (2) as average value of numerous studies and also have the advantage of considering interurban transport separately for each polluting factor. Applying these unit costs to the amount of each polluting factor emitted by each transport mode produces the final values of the social unit cost given by the pollution on each mode of passenger and goods transport.

POLICY OF PRICES: CASE OF MADRID–SEVILLE

Elasticities

Once the chosen methodology has been defined, it is necessary to model transport demand with the aim of simulating the effects on modal distribution of the price variations of each mode as a consequence of introducing the optimal price. For this reason, the values of the price elasticities of the demand for each mode of transport have been used, as well as those values relative to the alternative modes obtained by Coto-Millán et al. (17). In relation to the values of these elasticities shown in Table 1, it is worth pointing out major rigidity of the prices of petrol and diesel and the few substitution relationships between the various modes of transport.

Results

Table 2 shows the values obtained for each of the external social cost components per passenger kilometer in the Madrid–Seville corridor for each mode of passenger transport. The results are presented by these four main cost categories and by mode [road transport (car and coach), rail transport, and air transport]. These values have been ascertained with base year 1991 to have a horizon similar to that of the implementation of the high-speed train and being thus able to compare both policies efficiently. Moreover, as the AVE transports only passengers, only the external social costs of the passenger transport market have been estimated. The highest value of external social cost is for the car (5.18), and the coach is the transport mode with the lowest external cost (1.39). Accident cost represents the highest value of car external social cost, according to Nijkamp (18). The specific fuel taxes would have to be discounted from these values.

Once the social costs for each externality have been valued, the optimal price and the associated traffic volume for each mode of transport have been jointly determined with the use of price elasticities of demand. The obtained results, shown in Table 3, indicate that the introduction of a price equivalent to the marginal social cost in the Madrid–Seville corridor, within the internalization process of the multiple externalities on each mode of transport, would probably give rise to a sharp change in modal distribution of interurban passenger and goods transport. For example, if the base scenario (a value of human life of 0.8 million euros, special fuel taxes discounted) is taken into account, only the car would lose nearly four percentage points of modal share, passing from 52% in 1991 (Table 4) to 48.15%, which would be produced if the charge were applied. Consequently, this charge would mainly have effect to the benefit of the train, whose rate would be increased (Table 3).

One cause of this process is that competition between the various transport modes of passengers and goods takes place mainly (19) with the use of the components of the generalized cost (time, reliability, comfort, safety, etc.) and, to a lesser extent, through the fare price, as inferred from the low values of the price elasticity of the competing models. However, from the point of view of social benefit, the application of a policy of optimal prices based on the marginal social cost would have generated a social benefit of 4.5 million euros (2001) (area HLE in Figure 1) in the Madrid–Seville corridor for the adopted base scenario.

INVESTMENT POLICY: CASE OF MADRID–SEVILLE AVE

Impact on Modal Distribution

The high-speed train, AVE, which uses the standard European gage, started operating in the Madrid–Seville corridor in April 1992. This new mode of transport is characterized by its high speed (average travel speed of more than 200 km/h), more than double that of conventional trains, and its high infrastructure cost, with a fixed character almost independent of the number of transported passengers. Therefore, it needs to attract high levels of demand to achieve an acceptable level of profitability. The implementation of high-speed rail brings about a significant reduction in the generalized cost of the railway mode. This reduction does not take place in the monetary component of said cost, but it does in the other components (time, comfort, etc.).

AVE’s implementation produced two clearly visible effects on transport demand—through the subsequent heavy reduction in the value of the nonmonetary components of the generalized cost. These two effects are called “induction” and “substitution,” and they relate to the journeys that would not have taken place if this service did not exist and the journeys that would have taken place in another mode of transport, respectively. Given the large extent of the substitution effect, the implementation of the high-speed train produces significant effects on the demand for the remaining modes of transport that compete with AVE in the Madrid–Seville corridor. Apart from the almost complete disappearance of conventional trains in this corridor, the implementation of AVE has triggered a fall of nearly 50% in air traffic on the Madrid–Seville corridor. For the car, losses are lower than in the above cases, being nearly 30% in the corridor. Finally, with regard to the coach, it does not appear to have suffered a strong impact in long-distance corridors (11% of losses), as both products have a low level of substitution between them.

The high-speed train is the transport mode with the lowest generalized cost in the Madrid–Seville corridor. These differences in the

<table>
<thead>
<tr>
<th>TABLE 2 External Social Costs of Passenger Transport Modes in Madrid – Seville Corridor (without discounting taxes)</th>
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<tbody>
<tr>
<td>Car</td>
</tr>
<tr>
<td>---</td>
</tr>
<tr>
<td>Congestion</td>
</tr>
<tr>
<td>Infrastructure</td>
</tr>
<tr>
<td>Accidents</td>
</tr>
<tr>
<td>Environmental</td>
</tr>
<tr>
<td>Total</td>
</tr>
</tbody>
</table>

SOURCE: Own work from the methodology mentioned in the text.
generalized costs have provoked a dramatic change in the respective shares of transport modes, with the train as the main way of transport instead of the car, as in the past. As Table 4 shows, the bus has lost some passengers while plane and conventional train have suffered dramatic reductions in their use. In this sense, it is worth pointing out that rail becomes the dominating mode in the Madrid-Seville corridor, exceeding the car's market share—a rare case in the Spanish transport market.

Cost-Benefit Analysis

A generalized methodology has been used here, such as the one used by Dodgson (20) and widely described by De Rus and Inglada (21, 22). The considered cost–benefit areas are shown in Table 5. The costs include fixed component (infrastructure), semifixed (trains), and variable (operating costs). Prices (net of tax) of the infrastructure, trains, and operating costs measure opportunity costs, except in the case of labor (22).

The following benefit issues have been considered:

- Reduction in other generalized cost components of travel (comfort, security, etc.),
- Reduction of traffic accidents (road and rail),
- Revenues from operation of the project, and
- Cost reduction of maintenance and repairs of road and conventional rail track.

TABLE 5 Social Benefits of High-Speed Train in Madrid-Seville Corridor

<table>
<thead>
<tr>
<th>Benefit Area</th>
<th>AVE's Basic Benefit</th>
<th>Most Favorable Scenario</th>
</tr>
</thead>
<tbody>
<tr>
<td>Costs</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Infrastructure</td>
<td>2356.3</td>
<td>1987.6</td>
</tr>
<tr>
<td>Residual value</td>
<td>179.9</td>
<td>62.1</td>
</tr>
<tr>
<td>Trains</td>
<td>591.6</td>
<td>691.7</td>
</tr>
<tr>
<td>Maintenance</td>
<td>398.1</td>
<td>433.0</td>
</tr>
<tr>
<td>Operation</td>
<td>1401.6</td>
<td>1713.9</td>
</tr>
<tr>
<td>Time savings for the users provided by</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Conventional rail</td>
<td>415.2</td>
<td>543.5</td>
</tr>
<tr>
<td>Car</td>
<td>48.1</td>
<td>63.0</td>
</tr>
<tr>
<td>Bus</td>
<td>20.7</td>
<td>26.4</td>
</tr>
<tr>
<td>Air transport</td>
<td>21.7</td>
<td>28.0</td>
</tr>
<tr>
<td>Generated journeys</td>
<td>1072.8</td>
<td>1406.6</td>
</tr>
<tr>
<td>Reduction in the costs of</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Conventional rail</td>
<td>203.1</td>
<td>265.5</td>
</tr>
<tr>
<td>Air transport</td>
<td>209.0</td>
<td>288.8</td>
</tr>
<tr>
<td>Bus</td>
<td>19.5</td>
<td>25.5</td>
</tr>
<tr>
<td>Operating costs of cars</td>
<td>239.7</td>
<td>314.1</td>
</tr>
<tr>
<td>Congestion</td>
<td>11.3</td>
<td>15.9</td>
</tr>
<tr>
<td>Accidents</td>
<td>116.1</td>
<td>218.9</td>
</tr>
<tr>
<td>Environmental</td>
<td>62.5</td>
<td>88.9</td>
</tr>
<tr>
<td>Maintenance (other modes)</td>
<td>139.8</td>
<td>183.0</td>
</tr>
<tr>
<td>Net present value of AVE</td>
<td>-1990.1</td>
<td>-1295.7</td>
</tr>
</tbody>
</table>

*Maximum value of accidents, GDP growth of 3%, 40 years of project duration, and the consideration of the shadow price of the labor factor.

SOURCE: Authors' work from the methodology specified in the text.
Results

The benefits and costs of the introduction of the high-speed train in Spain are summarized in Table 5. The economic evaluation made through the cost–benefit analysis of the project indicates that the costs of this project exceed the benefits provided. The outcome is negative and mounts to 1,295 million euros (2001) in the most favorable scenario (40 years of project duration, maximum value of human life, growth of 3% in gross domestic product, etc.). Changes in the resultant NPV and the structure of benefits under the various hypotheses do not modify the main findings. The basic reason for this negative result lies in the very low level of demand, which means that the willingness to pay for the capacity may be lower than the costs of said capacity. In this sense, in comparison with other modes of transport, the high-speed rail’s profitability depends much more on the rest on the density of traffic on the corridor, as the supply of additional rail service units includes a much lower additional cost due to a strong effect of the economies of scale. Therefore, this type of policy intended to improve railway infrastructure, in connection with supply, with the subsequent high reduction of the time component of the generalized cost of the railway mode, appears to be very efficient in altering modal distribution, although with a high social cost.

CONCLUSIONS

This study has compared the results obtained from the application of the different transport policies—price and investment—that pursue the objective of reducing negative external effects in the Madrid–Seville corridor from 1992 until the present. An initial conclusion is that with the alternative based on the internalization of the externalities through an increase in the prices of transport modes, modal distribution suffers changes of little relevance. The introduction of the new and modern high-speed train in the railway transport mode has a major impact on the passenger transport market, which makes high-speed rail a predominant means of transport for that corridor, an uncommon case in Spanish transport market. This effect occurs only in the passenger transport market as the AVE does not transport goods. The conventional rail remains almost exclusively for goods transport and has a broad margin of capacity, given the release produced in passenger transport with the implementation of the AVE.

However, to compare strictly both alternatives, it is necessary to use an approach based on the social benefit variations. In line with this, the cost–benefit analysis carried out for the high-speed train shows that the social cost implied by the implementation of the high-speed train exceeds 1,295 million euros (2001) for all the considered hypotheses, as the improvements and benefits derived from time saving, the reduction of accidents, and other costs cannot compensate for the high cost of the infrastructure used by this mode of transport. Without any doubt, on corridors with higher traffic volumes, as, for example, Paris–Lyon, this alternative would generate an increase in the social benefit. However, an increase on the modal prices equivalent to the external marginal social cost would have implied a social benefit of 4.5 million euros (2001) in the base scenario studied. Definitely, from the analysis made, it can be concluded that from the point of view of economic efficiency and social benefit optimization, the high-speed train should not have been implemented in 1992 in the Madrid–Seville corridor. Moreover, this conclusion is strengthened by the fact that that year, and on the same corridor, important actions for the improvement of road and airport infrastructure were carried out. Other transport policy approaches, such as the introduction of an optimal modal price based on the respective marginal social costs, would have increased social benefit. The introduction of a high-speed train has brought a marked change in the modal distribution, albeit at a negative social benefit.

Therefore, from the results obtained in this investigation, the necessity to introduce higher economic efficiency in the transport market through the application to each mode of transport of a price based on the marginal social cost can be inferred. This is how the numerous negative external effects relative to passenger and goods transport are internalized. In the case of road transport, this internalization could be carried out by electronic toll or, if that was not possible, by the imposition of a specific tax on fuel-petrol and diesel. Through this method, an increase in the social welfare would be achieved.

In the field of infrastructure policy, investments that may involve a greater balance in terms of social welfare should be covered for the sake of higher economic efficiency, as shown by the economic theory.

Therefore, future transport policy should be based on the internalization through the prices of negative externalities and on the investment in infrastructure projects that present better balance in terms of social welfare. In this sense, probably other corridors with characteristics different from those of the one studied would have constituted more adequate scenarios in 1992 for investments in the improvement of the railway service which would have made it possible for this means of transport to strengthen its weak present role without bringing about a significant reduction in social welfare. The results obtained for the Madrid–Barcelona corridor (23) confirm that supposition. Further studies of other corridors would be necessary to confirm these conclusions.

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